

Contractor Report for NAS5-99094

Final Report for Option Year 1

Period Covered: December, 1998 through November, 1999

General Discussion

Contract NAS5-99094 was initiated on December 1, 1998. The subject contract contains 5 tasks covering specific activities in support of 3 major sensor programs, each with a separate NASA Principal Investigator (PI). Accordingly, the bimonthly narrative is organized such that each of the programs are discussed separately with individual task activities presented within each of the programs. Acronyms are used throughout the report to keep the writing succinct. An attached glossary contains definitions for these acronyms.

Airborne Topographic Mapper (ATM)

Task 1 - Mission Planning and Execution and Sensor Operation and Calibration

Planning of the Greenland AIM and U.S. ALACE field missions began early in Option Year 1. The flight line planning required iterative exchanges with the various scientific groups that have an interest in the final data products. The planning effort attempted to maximize the data gathered per amount of flight time and considered the constraints of the particular aircraft platforms used for the missions, the scheduled availability for the use of the aircraft, and the budget for the aircraft time.

The planning for the ATM missions also involved working with NASA mission managers to develop an Operational Safety Directive (OSD) which is required for all flight activities involving NASA civil service or contractor personnel. Separate OSD's had to be developed for the Greenland, Navassa, and ALACE deployments. In this regard, EG&G recommends that NASA develop OSD's that can be used for longer periods of time when circumstances such as the aircraft and instrumentation remain essentially the same. This would reduce considerably the amount of redundant work involved with the advanced planning. This year the major campaigns were conducted with the ATM in Greenland, along the U.S. east and Gulf coasts, and over the Caribbean Island of Navassa.

The main theme of the 1999 Greenland campaign was to reoccupy the flight lines over the

northern half of the massive ice sheet originally surveyed in 1994. In addition, there were several lesser objectives that included (1) the occupation of two future exact-repeat orbit of Ice Cloud and Land Elevation Satellite (ICESat) (Dr. Jay Zwally, GSFC) , (2) the survey of a section of northern Greenland where subsurface tectonic activity was suspected (Dr. Mark Fahnestock, U. of Md.), (3) survey a grid over a section south of the Petermann Glacier where anomalous gravimetry measurements have been observed (Bea Csatho, Ohio State Univ.), (4) test the recently developed JPL Europa ice-penetrating radar (Dr. Alina Moussessian, JPL), and (5) perform a 100 km long check of methods proposed to validate the ICESat over ice (Dr. Robert Thomas, EG&G). These missions were also flown the the U. of Kansas CARDS (Coherent Arctic Radar Depth Sounder) and the JPL Europa ice- penetrating radars. The two radars did not operate simultaneously since they were installed with shared dipole antennas.

The 1999 ALACE field program was aimed at (1) gathering post-storm coastal morphology information along the North Carolina coast following the passage of Hurricanes Dennis and Floyd, (2) surveying the coastline of Georgia and Florida from Savannah, GA to Key Biscayne, FL, (3) mapping the Bolivar Peninsula located near Galveston, TX, (4) surveying the Lisbon Bottoms section of the Missouri River flood plain located near Columbia, MS, (5) mapping Long Island, NY, (6) completing a bi-annual survey of Assateague Beach, and (7) conducting beach and wave mapping measurements in the vicinity of the Outer Banks of NC.

A special mission to acquire topographic information was flown over the Carribean Island of Navassa from a staging airport located at Guantanamo, Cuba. There has been considerable scientific interest in the island due to the diverse and unique flora and fauna that grow on the uninhabited island. The Navassa mission was coordinated with Dr. James Garvin (GSFC). Additional information on Navassa can be found on the Internet at denali.gsfc.nasa.gov/navassa.

Greenland Mission Planning and Execution

The bulk of the planning for the Greenland mission involved checking that the flight trajectories occupied during the 1994 survey were consistent with the way points that had been entered into the realtime navigation system. Each of the 11 missions had to be individually checked using *missdist*, a Fortran program developed by EG&G during the previous contract. The *missdist* software differences the trajectory from the earlier survey against the great circle path between each pair of way points on a line-by-line basis. Where deviations in excess of 100 m were found intermediate way points were developed if they could be spaced 20 or more kilometers apart. If the previous survey appeared to meander more than could be practically fixed with the generation of new way points, a look-up table was developed from the trajectory in a GPS "GGA" ascii format that is read by the XTRAC realtime navigation software discussed in the navigation section below.

The other required flight missions associated with Greenland activities 2 - 5¹ were essentially new and could be occupied by way points entered into the CDI realtime navigation system discussed in the navigation section below. In most cases the way points were provided by the cooperating investigator, but in the case of the ICESAT exact-repeat orbits, the way points were calculated at 100 km spacings. In the tests of the Europa radar, some of the tests were conducted over the Jakobshavn Glacier using information from earlier trajectories and the XTRAC realtime navigation software. Considerable effort was made to merge the requested Greenland activities 1 - 5 with the original 11 missions flown over the northern half of the ice sheet in 1994. As a result of the planning all of the requested field measurements were acquired in just 14 missions. The locations of the flight tracks surveyed during the 1999 AIM deployment to Thule, Greenland are shown in Figure 1.

The Greenland deployment began May 6, 1999 with departure from Wallops. A total of 14 missions were conducted in Greenland between May 7 and May 26. The field campaign went nearly flawlessly, there were no major instrument or aircraft related problems, and the weather was extremely cooperative. In fact, flights were flown on all days that the airfield was open in Thule. A calibration flight was conducted from WFF both before and following the field deployment. Data was acquired on all mission with both the ATM-1 and ATM-2 scanning laser altimeters. All ATM and GPS data was backed up to CD-ROMS in the field. Preliminary processing in the field was conducted on selected portions of missions and the data appeared to be of good quality. The only instrument problem noted concerned the ATM-2 system, which used a Continuum laser for the first time in Greenland. The laser shut down due to thermal regulation problems and 15 minutes of ATM-2 data was missed during 1 mission. Immediately following the mission, thermal blankets were procured and installed around the laser head. No further problems were encountered. Aspects related to the realtime navigation and GPS operation will be discussed in a separate section.

ALACE Mission Planning and Execution

A general strategy for planning and executing ALACE missions has evolved over the past several field seasons. For most coastlines, the location of the beach/water interface is not well enough known to permit reliable use for generating either way points or a GPS "GGA" ascii file for use with the XTRAC realtime navigation software discussed below. The approach therefore has generally been to fly an initial pass as close to the beach/water interface as possible using a combination of nadir pointed video and pilot hand steering. On subsequent passes the projected ground track on the XTRAC video screen is used to progressively move the location inland, but overlapping by ~30% with the initial pass. The realtime XTRAC video display reveals any areas of non overlap which can then be filled in on a third pass. When long sections of coastlines are to be surveyed, which was the case with the Savannah, GA to Key Biscayne, FL, staging sites are selected at intervals of 350 to 450 km. In conducting these mission two passes are generally made from a staging airport over a section of coastline about 200 km in length. One of the

¹Activities 2-5 in the Greenland Planning Introduction

passes is made as close as possible to low tide while a second pass is made landward with about 30% overlap. The landward pass provides information on dunes and features located behind the dunes. On the next survey day, a transit mission is flown from the current staging airport to the next staging airport located some 350 to 450 km away. The transit survey mission provides a single pass over the coastline between the two airports. Thus, the combination of two-pass and single pass on the transit mission yields three pass coverage of the coastline.

Several of the sites required mapping further inland than could be accomplished with the usual three-pass scenario. These included the mapping of the Missouri River flood plain at Lisbon Bottoms, the survey at Camp Lejeune, NC, and the mapping of the Bolivar Peninsula near Galveston, TX. At these locations the display from the XTRAC realtime navigation was used by the pilots to steer the aircraft from the initial flight line progressively further into the site while attempting an approximate 30% overlap with the preceding pass.

The two ALACE post-hurricane surveys were conducted with the ATM-1 and ATM-2 sensors mounted on the NASA P-3B aircraft. These sensors had been installed on the P-3B aircraft in early September in preparation for the planned Navassa survey in latter September. Both hurricanes hit prior to the Navassa deployment. After discussions with collaborators at the NOAA Coastal Services Center (Charleston, SC) and the USGS Center for Coastal Geology (St. Petersburg, FL) it was decided to use the larger, more expensive 4-engine P-3B aircraft. On both of these mission a single pass was made from north to south along the North Carolina coastline using trajectories developed from the data acquired over the coastline in 1998. A second pass displaced landward with 30% overlap was then made from south to north.

The remaining ALACE missions were conducted with a three man crew, an ATM-2 operator, an engineer to operate the realtime navigation system, and a ground GPS operator. On the GA/FL coastal survey, an additional ground GPS operator was borrowed from USGS to facilitate the transit missions between sites. This year the amount of equipment was lightened somewhat permitting the transport of the 3 EG&G engineers and all the needed calibration and ground GPS equipment within the Twin Otter aircraft during transits between locations to be surveyed. This situation resolved a number of logistical problems and saved considerable money over commercial transportation of one or more of the engineers needed for the ATM ALACE surveys.

Navassa Mission Planning and Execution

Planning for the Navassa mission was somewhat simpler. The precise location of the island and its orientation were not known accurately enough to plan all of the flight lines necessary to accomplish the desired survey of the island that was about 1.5 km wide and 2.5 km long. Thus, EG&G recommended a plan to simply fly down the long axis of the island using best judgement of the pilot in realtime. The locations of the flight line at both ends of the island was then captured with the CDI realtime navigation system. On ensuing passes an offset on one or other side of the initial pass was progressively added until the flight lines contained about 30 %

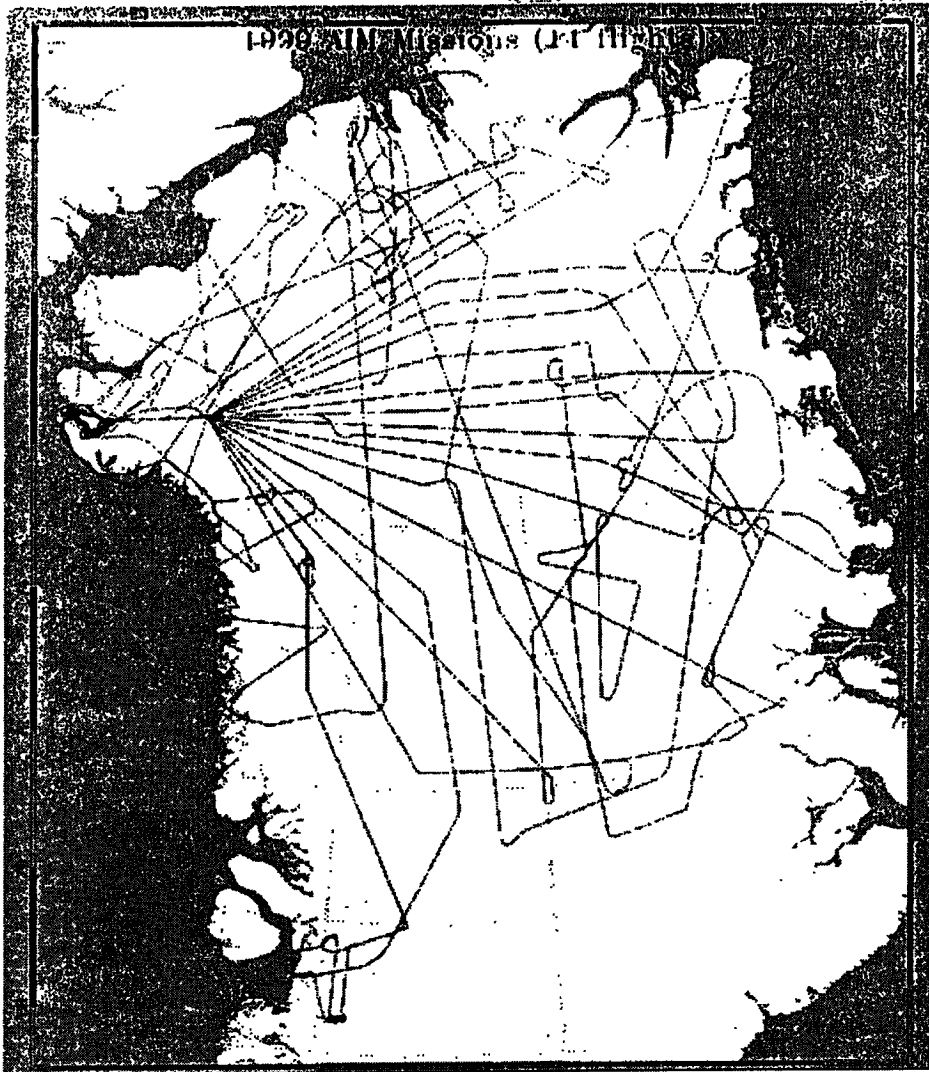


Figure 1. Map showing the distribution of flight lines from the 1999 Arctic Ice Mapping project in Greenland.

overlap encompassed the entire width of the island.

The survey of Navassa island was accomplished in a single ~4-hour mission staged from the U.S. Naval Base at Guantanamo, Cuba. The mission was conducted with no observed problems using a crew of 4 EG&G engineers and scientists. During the initial transit mission some imagery of the island was obtained with the NASA Advanced Solid-State Array Spectrophotometer (ASAS) passive spectro-radiometer.

GPS Field Activities

GPS ground and aircraft operation is required to support all ATM missions. The ATM field missions necessitated nearly two months of deployment away from Wallops. When combined with the numerous local missions and local tests and experiments, over 1,000 occupation² hours of ground GPS data were collected.

During the year there were four separate installations on two aircraft: two installations on the NOAA Twin Otter, and two on the NASA P-3B, in support of missions from the Great Lakes to the Gulf of Mexico (and many points between) and from Greenland to Cuba. In addition to supporting our own data collection efforts, GPS equipment in our control was also loaned to experimenters mapping ice flows in Antarctica and Greenland and to experimenters mapping hurricane storm surge during the 1999 hurricane season. In some cases, experimenters are not completely familiar with the operation of equipment, so that instruction and long-distance advice are important components of the equipment loan. Several occasions have arisen, this year, where because of our established expertise in GPS matters, we have been consulted with regards to GPS operations aboard the NASA aircraft by non-project and non-facility personnel.

Because of the extensive scope of our missions, there have been thirteen new benchmarks surveyed this year: ten new occupations, two replacements because of destruction of previously occupied sites and a new site at Wallops which is a stable, permanent mark that no longer requires the obstruction of aircraft ramp areas or runs the risk of disturbance by aircraft prop wash. The new site (north of building N-159) also has access to electrical power, obviating the need to supply electrical power through the use of a running automobile/inverter system. This benchmark is now our main reference mark for all missions flown from Wallops.

This summer, the project focused on trying to resolve some nagging biases remaining in the solution of antenna location. A series of ground tests was devised to try to better understand the unknown antenna location. As a result, it was discovered that one model of the standard antennas in use was not yielding the expected results, and that the use of that type of antenna adversely affected the quality of the data solution. The first step taken was to avoid using that style of antenna for the fall series of experiments. By the end of the year, a version of software

²Occupation hours are calculated as hours of collection over benchmarks, and does not include multiple receiver operation at a given site

used to calculate antenna position was created that will now handle the unique qualities of this antenna. More on this issue is discussed in Task 3.

This past year also marked two anniversaries with potential for disaster for GPS and data collection in general. During August, the GPS system passed thru its 1023rd week since inception. Many receivers and software to operate and collect data from the receivers would be affected by the inability to count beyond the number 1024, thus resetting back to 0, and in essence, restarting the "GPS clock". The remedy for the original 1970's shortsightedness was to replace receiver firmware and software with EOW (End of Week) compatible versions. At the same time there was concern over the approaching Y2K event. Therefore, firmware upgrades were performed on all eleven GPS receivers, software was replaced on ten computers and Y2K checks were performed on the combined systems. All upgrades were successful, both anniversaries passed unnoticed.

Field tests this autumn of improved receiver power harnesses will lead to a reduction of weight to be transported or shipped while on deployment. The use of lighter weight (and less expensive) power inverters are the direct result of this straightforward wiring concept improvement. The purchase of a second lighter-weight inverter, along with the acquisition of a second precision survey grade antenna (planned for FY2000) would allow complete two-system redundancy for maximum efficiency in field work. One area that needs attention in the coming year is in the production of data archives while in the field (especially during the weight restricted shoreline mapping missions). At present we have a working system, but that system is cumbersome in terms of the number of steps needed to preserve the data from up to four separate receivers, and more importantly, allows ample room for oversight in terms of the multiple copies needed to ensure the safekeeping and transfer of the data until formal saves may be completed.

Realtime Navigation on ATM Mission

All ATM flights require some form of realtime navigation support from the science crew. These navigation requirements fall into three specific types. The first is the need to guide the aircraft along a great circle course between pairs of predefined way points. The second requirement is to provide pilot guidance to enable him or her to hand-fly a non-great circle course track, usually defined by the ground track or scan swath from a previous ATM flight. The third requirement is to cue the pilot to provide area coverage using the ATM scan swath. All three types of navigation require accuracy of about 100 meters or better.

The first type of navigation has been done successfully for years by EG&G personnel by using a NASA-developed DOS-based navigation system known as CDI. In addition to providing visual guidance cues to the flight crew, CDI can also provide electronic steering commands to the aircraft's Instrument Landing System, allowing flight lines hundreds of kilometers in length to be flown accurately and repeatably with little or no pilot steering input. CDI works quite well and EG&G recommends no changes to this system, with one exception. This involves a known bug in which the CDI software can reverse its steering cues when following a due north or due south

course. The problem appears to be a trigonometric quadrant ambiguity, probably triggered by some form of numerical roundoff error since it manifests itself with apparent randomness. The problem is uncommon, difficult to reproduce and can usually be handled by switching to another navigation technique until the software corrects itself. For these reasons we do not assign a high priority to correcting the problem, though it should be fixed as time permits.

The need to follow meandering (non-great circle) flight paths first arose during beach-mapping activities and later became a part of Arctic ice mapping work as well. EG&G personnel developed a Linux-based new software tool called XTRAC to provide visual cues that enable a flight crew to overfly a previous survey or other predefined path. XTRAC has been in service for two years. It displays the desired scan swath coverage, which is most often defined by a previous ATM survey, along with the scan swath of the current flight. This makes it useful for area mapping as well, since the pilot can see the current scan coverage and adjust the aircraft's path to "paint" the desired area with coverage. CDI with its offset feature is also used for area coverage in certain cases, particularly in island surveys such as Surtsey and Navassa. Here, XTRAC is still useful as a visual check on the coverage obtained.

Like CDI, XTRAC has proven itself to be stable and almost 100% reliable in working as needed over the course of several field campaigns. However it does have problems displaying a desired flight path in certain very specific circumstances, which can include meandering runs down glacier valleys. It presently is not known whether this problem lies in XTRAC itself or in the input data, though it is most likely some combination of the two. Since published ATM results show that the outlet glaciers are of prime scientific interest, EG&G recommends that this particular problem be thoroughly investigated and resolved before the May, 2000 Arctic deployment.

Finally, we recommend that all elements of the navigation system aboard the NASA P-3 be made doubly redundant. In previous years the CDI system was made doubly redundant, but the XTRAC system has resided on only one computer. It is expected that XTRAC will be relied on more heavily in future missions, and a failure of that one system could result in lost science and increased costs. EG&G recommends that one of the two redundant CDI computer systems in the navigation rack be made into a dual-boot Linux/DOS machine with CDI and XTRAC installed. This would make it impossible for a single point of failure to jeopardize a mission.

Task 2 - Data Processing Cataloguing and Archiving

Between 12/1/98 and 12/9/98, there were 5 East Coast Beach Map '98 flights and one Wave Map flight. Between 9/7/99 and 11/6/99, there were 14 East Coast Beach Map '99 flights, one Gulf Coast Beach Map '99 flight, one flight dedicated to a comparison between the GPS and INS systems, and two Wave Map flights. In addition, there were two engineering checkout flights

and a couple of Ground Tests conducted. All original level 0³ data was retrieved from the removable hard drives and transferred to CD-ROM disks, making two copies, one of which is stored in the EG&G Gaithersburg facility. Most of the level-0 data was processed to level-1⁴ and level-2⁵ stages. These were likewise transferred to CD-ROM disks for archiving and further processing. Only one copy of the level-1 data was made, but the level-2 data was made available to the scientific community and multiple copies were made as needed.

Between 4/2/99 and 6/16/99, there were 14 Arctic Ice Mapping (A.I.M.'99) flights plus two pre-mission and one post-mission flights and a half dozen Ground Tests for calibration. From 9/22/99 to 9/28/99, there were three Navassa flights. Also, on 10/19/99, an area was mapped near Lisborn Bottoms, MO. All original raw data (level 0) was retrieved from the removable hard drives and transferred to CD-ROM disks, making two copies, one of which is stored at the EG&G Gaithersburg facility. Most of the level-0 data was processed to level-1 and level-2 stages, and in some cases, to level-3. Until the data is approved to be shared with the scientific community, only 1 copy of the level-1 and level-2 output will be made. Upon approval, the level-3 data will have multiple copies made and distributed.

During the course of the year, the project changed from storing the CD-ROMs within their plastic cases (jewel boxes) in rotating towers, to an album style where the jewel box was discarded permitting nearly 300 disks to be stored in a single album. The albums are then placed in a storage cabinet until needed. The towers are now used to hold only the more frequently used level-2 processed data along with working backups of the computer system. We recommend that NASA consider moving to a denser storage medium during the coming year in order to cut down on the number of discs that are stored. For instance, a single Greenland mission will produce 3 - 4 CD-ROMs of data from one ATM resulting in 6 - 8 CD-ROMs of raw data. Another 6 - 8 CD-ROMs are generated in the level-1 processing and another 6 - 8 in the level-2 processing.

Task 3 - Data Analysis Interpretation and Reporting and Laboratory Analytical Support

PUBLICATIONS

Results were reported in several journal articles. During the year, six articles were either published or submitted for publication. One other was in preparation during the contract year and about to be submitted at the end of the year. The range of accomplishments are reflected in the many institutions of the coauthors/collaborators: NASA GSFC Laboratory for Terrestrial Physics; JPL; Ohio State University; University of Kansas; USGS; NOAA. We also contributed

³Level 0 is raw data recorded directly from the sensor

⁴Level 1 is the transformation from raw data into a form used for further processing

⁵Level 2 is a scaled integer binary file with elevations positioned in WGS84 coordinates

to two other publications on which we were not coauthors.

"Rapid Thinning of Parts of the Southern Greenland Ice Sheet," W Krabill, E Frederick, S Manizade, C Martin, J Sonntag, R Swift, R Thomas, W Wright, J Yungel. *Science*, v283, n5407, pp1522-1524. 5 March, 1999.

(Revised December 1998, accepted 2 January 1999) The article presented the changes observed between the 1993 and 1998 ice mapping missions flown on the WFF P3-B aircraft.

"Airborne Laser Study Quantifies El Nino-induced Coastal Change," A H Sallenger Jr., W Krabill, J Brock, R Swift, M Jansen, S Manizade, B Richmond, M Hampton, D Eslinger. *Trans. American Geophysical Union (Eos)*, v80 n8, pp89-93. February 23, 1999.

Presented some results from the October 1997 and April 1998 beach mapping surveys before and after severe winter storms. A modified version of this article appeared in *Earth and Space*, a journal for teachers and students of science, under the title 'Recent El Nino eroded US West Coast' (vol. 11, no. 8, pp. 5-9, April, 1999).

"Airborne Laser Mapping of Assateague National Seashore Beach," Krabill, Wright, Swift, Frederick, Manizade, Yungel, Martin, Sonntag, Duffy, Hulsander, Brock. *Photogrammetric Engineering and Remote Sensing*. v66, n1, pp65-71. January, 2000.

(Accepted 25 January 1999, revised 22 February 1999)

"20-Year Time Series of Greenland Ice-Sheet Thickness Change from Radar and Laser Altimetry," R. Thomas, C. Davis, E. Frederick, S. Manizade, W. Krabill, J. McConnel, J. Sonntag. Submitted to *Journal of Geophysical Research (JGR)-Oceans* 19 November, 1999. The paper compared the measurements of the southern Greenland ice sheet by the ATM over the period 1993 to 1998 against measurements from satellite radar during a slightly earlier period.

"Substantial thinning of a major east Greenland outlet glacier," R. Thomas, W. Abdalati, T. Akins, B. Csatho, E. Frederick, P. Gogineni, W. Krabill, S. Manizade, E. Rignot. Submitted to *GRL*, December 6 1999.

This paper about repeat measurements of the Kangerdlugssuaq glacier in eastern Greenland was in preparation throughout most of the year. Laser measurements of the ice surface and radar measurements of the bedrock, both collected during WFF P3-B aircraft flights, were processed and graphed. Various satellite measurements from 1966-1996 were combined with the airborne data to derive ice velocity, ice front positions, ice elevation changes, and ice thickness. Early in the year a version of the paper was submitted to and rejected by two journals. The paper was augmented with 1999 satellite photographs and was about to be submitted to *GRL* at the end of the contract year.

Calculation of Ice Velocities in the Jakobshavn Isbrae Area Using Airborne Laser Altimetry
Abdalati & Krabill *Rem. Sens. Envir.* v67 pp194-204 1/1999.

Comparison of Greenland Ice Sheet Topography Measured by TOPSAR and Airborne Laser Altimetry
Bindschadler, Fahnestock & Sigmund *IEEE Trans.G. & R.S.* v17,n5 pp.2530-2535

9/1999.

Airborne Scanning Lidar Measurement of Ocean Waves Hwang, Krabill, Wright, Walsh & Swift Nav. Res. Lab. memorandum NRL/MR/7332--99-8221 3/9/1999.

A workshop, "Mapping Surface Structure and Topography by Airborne and Spaceborne Lasers", sponsored by the International Society for Photogrammetry and Remote Sensing (ISPRS) was attended November 9-11 and a presentation given on recent ATM project activities.

ACTIVITIES AND RESULTS

A major milestone was achieved this year with the completion of the Greenland surveys remeasuring surveys from 5 years ago. The overall result shows that the ice sheet is in balance at higher elevations (above 2000 meter elevation), but in coastal areas there is overall thinning of the ice which in some glaciers reaches magnitudes of 10 meters per year. Over the entire ice sheet, the net ice volume loss was 51 cubic kilometers of ice per year, or about an average thinning over the whole ice sheet of 3 centimeters per year. These results are being prepared for a journal article to be submitted in January. There was much variability among glaciers, particularly in the north there were several which were either surging or recovering from a surge, showing areas of both thinning and thickening. In the south, the trend was for much more consistent thinning across all glaciers, particularly at lower elevations. More attention should be given to measuring outlet glaciers in the future for two reasons. First, it has become clear how active the glaciers can be and how variable is their behavior. All the factors affecting their dynamics are not well understood, and there are great differences in behavior between separate glaciers and also between different time periods for a single glacier. Second, the difficulty of flying a survey down a glacier still presents some challenges in guiding the aircraft precisely. The flying conditions are often difficult, including hazards such as fog, steep terrain, and rock outcrops. The comparison between repeated flights along a glacier show that often the surveyed swaths do not overlap, and the change measurement is not achieved. These observations will guide improvements to be incorporated into the realtime guidance of the aircraft during forthcoming glacier surveys.

Instrument calibrations and verification of instrument performance were provided for three campaigns. The beach mapping campaign from autumn 1998 was wrapped up. For the autumn 1999 deployments, verification and some preliminary calibrations were provided, with final processing still pending at the end of November. The spring 1999 campaign to Greenland is described in some detail after a summary of the others.

Range and mounting calibrations were finalized for the beach mapping data collected on the NOAA twin otter aircraft from September to December 1998 over U.S. coastline in these states: FL, AL, MS, LA, NY, MA, PA, OH. Processing was then completed, and the products archived on CD-ROM and distributed to NOAA, USGS, and to state agencies in NY, OH, and PA.

The ATM-1 and ATM-2 were installed in the NASA P-3 aircraft for several missions in September. The primary mission was a deployment to Guantanamo Bay, Cuba in order to survey the island of Navassa. Prior to the deployment, there were a local test flight and missions to assess beach erosion after Hurricane Dennis and again after Hurricane Floyd. Instrument data from ground tests following installation and from the test flights were analyzed to verify proper operation prior to the survey missions. Using preliminary calibrations and parameters, the post-Dennis survey was processed and delivered to USGS and NOAA within two weeks after the survey flight. Following the deployment to Cuba, a local flight over the WFF ramp was made and the instruments were removed from the P-3. Range calibrations were produced from ground tests and instrument parameters were derived from the consolidation of all the ramp passes. The results were good, with range residuals of less than a few centimeters for both instruments. Following the deployment, the instruments were removed from the P-3 and the ATM-2 was installed on the NOAA twin otter at the start of October. The usual calibration checks and mounting bias determination was conducted for the installation on the twin otter.

Preparations began in April for the field mission to measure the Greenland ice cap. Processing software was modified and tested to handle a new mode in which the range bit-weight is changed from 156 picoseconds (ps) to 312 ps to allow a larger span of measurable range; the range calibrations were shown to be unaffected by operation in the new mode. Operation of ground-test software was verified on the Sun computer onboard the P3 aircraft.

The field mission itself took place May 6-27. Daily analysis tasks included pre-flight and post-flight checks of the instrument operation and range bias measured during ground tests. Flight data was examined daily to verify instrument operation and proper receiver gain settings. Also, a limited amount of data over sea ice and over the Thule airport ramp were processed to the level of georeferencing (qfit) using preliminary mounting parameters and GPS trajectory in order to more completely demonstrate proper operation. One final mission was flown over the Wallops airport on June 16. June and July were spent calibrating and preparing to process the data collected during the May field mission.

Range calibrations were developed from the ground tests conducted before and after each flight. 95 calibration files were collected for ATM-1 and 76 files for ATM-2 during the month. A table of measured distances and a table of file names and settings were made. The tables and laser data were then used to create from each ground test file a range calibration curve that considered both receiver and transmitter energies. These calibrations were then consolidated into a single calibration for each instrument setting.

Flight data collected over sea ice and over the Thule and Wallops airport ramps were then processed to produce calibrated laser ranges. These were used to estimate the instrument mounting biases and the range residuals for each pass. The parameter solution for ATM-2 showed good (~5 cm) RMS range errors and a zero mean range bias. However, the solution for ATM-1 remained with a 7 cm mean range bias after reexamination of range calibrations and flight data over the Thule, Greenland and Wallops airport ramps. Processing of all of the ATM-2 data was completed through processing programs *newvalT*, *qfit*, and *icess*. An indication that we

achieved our accuracy objective comes from an comparison of surveyed elevation at all locations where a flight from one day crossed a flight from another day. The elevation difference at total of 332 crossings yielded an RMS of 9 cm.

Mounting Bias Estimations

Mounting biases for the airborne terrain mappers primarily refer to pitch and roll angles which change slightly with each new or re-installation of the instruments on an aircraft. However, there are two other mounting angles (scan azimuth bias and " β ", associated with the exit angle of the laser beam) which also change, as well as an off nadir angle which theoretically should not change but which has never been determined with sufficient confidence to be fixed in all data reductions. Further, any errors in the off-nadir angle are difficult to distinguish from ATM ranging bias, which is also frequently uncertain.

ATM mounting bias estimations were made for the 1999 Greenland ice mapping campaign and for the ALACE beach mapping missions in the normal manner of processing data from aircraft passes over surveyed ramps (plus some data over sea ice) to estimate the 5 angles associated with the instrument configuration plus the ranging bias. This has to be done using multiple ramp passes at multiple altitudes in order to resolve bias and off nadir angle. The beach mapping was performed primarily using ATM-2, but some mapping was also done with ATM-1. In general, the mounting biases for beach mapping were consistent in the sense of having reasonably constant day-to-day mounting biases and relatively small range biases. The parameters estimated for the Greenland campaign were somewhat less consistent. The clearest inconsistency was in the pre-mission pitch biases, which differed systematically from the post-mission pitch biases almost every day. The only reasonable explanation for this pre-post-mission change is errors (or variations in errors) in the aircraft INS attitude output, particularly since the same changes were observed for ATM-1 and ATM-2. Allowing for the existence of a pre-mission-post-mission change in ATM pitch mounting relative to the INS (and assuming post-mission estimates to be a more valid representation of ice mission parameters), reasonably satisfactory mounting biases were estimated for ATM-2, allowing for a systematic change in a couple of parameters in the middle of the mission (explicable as being due to the mounting of a camera in the vicinity of the scan mirror). For ATM-1, extensive analysis was unable to obtain a set of mounting parameters consistent for the Greenland campaign without allowing for a range bias, for which a value of 7 cm was estimated. No satisfactory explanation for the existence of a bias of this magnitude could be found. However, comparison of ATM-1 and ATM-2 elevation measurements on the Greenland ice sheet confirmed that such a bias was needed to obtain consistency between the instruments.

In addition to the ramp pass estimations of mounting biases, ATM-2 data for the 1999 Greenland campaign was also analyzed over the ice sheet at points where trajectories for different days crossed. Using data at trajectory crossings in the form of the *icess* platelets, it is possible to estimate roll errors for each pass, along with an overall elevation difference. These analyses indicate that expected roll errors are on the order of 0.03 deg, with possible excursions to 0.05-

0.06 deg. In general, it was not possible to associate roll errors with elevation or geographic location.

Interpretation and Recommendations

It is clear from the data analysis results that one of the major limitations on ATM elevation accuracy is due to INS attitude errors. Although various procedures can be used to estimate roll (and sometimes pitch) errors using ATM data, it is difficult to estimate more than a limited number of points. It is well known that GPS position data can be theoretically combined with INS data to produce much more accurate attitude data than is presently produced by the current Litton or Honeywell INS systems. And commercially available instruments have also been developed incorporating this data combination. Accordingly, it is recommended that either such an instrument be purchased for ATM usage, or that the software be developed to combine the output from an INS system (preferably co-located with the ATM) with GPS data for the production of pitch and roll data with an order of magnitude better accuracy than that presently available.

It should be noted that the primary uses of ATM data in the past several years have been comparisons of elevations from overflights several years apart, in which average elevation changes over quite large areas are desired. In this utilization, ATM elevation measurement errors are averaged along with actual terrain elevation changes, so that relatively short wavelength (e.g., several of kilometers) ATM errors can be averaged out. In the next couple of years, there will be more emphasis on GLAS calibration, for which ATM elevation errors over the shorter wavelengths will become more important. It is quite possible that the basic INS data (rotation rates and accelerations), when processed in conjunction with the GPS data, will be able to also improve the aircraft position data. For this reason, it will be preferable to develop software to combine GPS/INS data rather than purchasing an instrument for simply providing improved pitch and roll data.

GPS Positioning and Data Handling Methodology

Precise GPS positioning is a key enabling technology behind the ATM system. EG&G personnel have developed and applied GPS positioning techniques which allow ATM survey results to be expressed in terms of a globally valid, widely understood reference frame. This greatly facilitates the effective use of ATM data by outside organizations, and makes the large body of ATM ice and beach surveys a true scientific and national asset far into the future. Decades from now ATM surveys could prove to be a tremendous help to scientists as a baseline data set for long-term change detection. This is possible in part because the current state of GPS positioning technology allows us to express ATM results in a universally meaningful form. Still, improvements can be made to certain aspects of our GPS positioning work.

EG&G scientists use two main analysis tools to interpret GPS data. The first of these packages, known as GITAR, was developed by EG&G under contract to NASA and has supported the AOL/ATM project almost since its inception. GITAR analyzes GPS data from pairs of receivers

in a differential mode, which yields very accurate positions for a fixed or mobile receiver relative to a fixed base station receiver whose position is known *a priori*. The other major GPS software package is JPL's GIPSY/OASIS II software, referred to as Gipsy. Gipsy uses an undifferenced approach and can accurately determine the position of a single fixed receiver or a network of fixed receivers, referenced to the International Terrestrial Reference Frame (ITRF). Taking advantage of the natural synergism of these two techniques, EG&G typically undertakes a Gipsy analysis using all available data at ATM ground stations to determine their positions. These positions are in turn fed into GITAR, which determines the trajectories of ATM remote sensing aircraft relative to the base station. Occasional cross-checking between the two packages is done by using GITAR and Gipsy to determine the relative positions of multiple ground stations when they are simultaneously active.

Cross-checking of this kind recently revealed some discrepancies between Gipsy and GITAR relative height components of certain baselines. The discrepancies were up to several centimeters in magnitude and always involved an Ashtech 700718 ("new-survey") style antenna at one end of the baseline. Extensive investigation of the problem revealed that this particular antenna design has an unusually pronounced dependence of apparent phase center location on satellite elevation. Depending on the analysis technique used and on the tropospheric conditions, this effect was found to bias GITAR and Gipsy height solutions differently. Although the "new-survey" antenna has the most pronounced effect, all GPS antennas are affected, to some degree, by phase center dependence on satellite elevation. To account for and remove this, EG&G personnel located the results of a National Geodetic Survey experiment which give the corrections needed to remove the phase center variation effect for many commonly-used GPS antennas. We have also developed and successfully tested a software tool which implements these corrections, by taking a regular Rinex-format GPS data file and outputting a modified Rinex file to which the appropriate corrections have been applied. An example of the improvement yielded by this process is shown by an analysis of data from a ~24 hour short baseline (~100 m) occupation at Wallops. The baseline consisted of an Ashtech choke-ring antenna at one end (marker N159) and an Ashtech new-survey antenna at the other end (marker PT16). These data are shown in the table below:

N159-PT16 Relative Heights		
Situation	Height (cm)	RMS of fit (cm)
Gipsy with corrections not applied:	23.1	1.04
GITAR with corrections not applied	30.7	1.28
Gipsy with corrections applied	27.8	1.00
GITAR with corrections applied	28.9	0.62

In this case, a nearly 8 cm discrepancy between GITAR and Gipsy height estimates without the phase center variation corrections shrank to an acceptable 1 cm difference when the corrections were applied, and the rms fits to the data also improved markedly. These results are representative of a number of similar experiments.

Given such uniformly positive results, EG&G recommends that the phase-center variation correction software become a standard part of all GPS data processing. The NGS antenna database contains all antennas which are currently used in the ATM project, with the exception of the aircraft avionics antenna. Therefore we further recommend that an experiment be conducted to measure the phase center variation properties of this antenna in all of its installed configurations, since the presence of the airframes will likely change the properties of the antenna. We also point out that only data collected using the new-survey antenna are significantly affected by this change. None of the major Greenland field campaigns (1993-1994, 1998-1999) used this antenna as a base station antenna, nor have any of the beach-mapping campaigns.

EG&G also recommends that investigations be carried out to determine the feasibility and desirability of incorporating multiple ground stations into kinematic aircraft positioning. Currently, the GITAR software utilizes data from only one base station and determines the position of the aircraft relative to it. But the use of multiple reference stations, in theory, should help reduce the effects of tropospheric refraction and orbit error, provide improved positioning geometry, reduce base station multipath error and add redundancy.

Task 4 - Network Development and Maintenance

Major network maintenance and upgrade activities conducted under Task 4 included the upgrade of the operating systems on all of the Sun workstations to Solaris 7.1. Numerous hard drives and other peripherals were replaced or added as needed. Also installed and monitored various network security tools. A number of requested features were added to mplot, the projects universal plotting tool. These included polar and other map projection coordinate systems. Many support tools, such as PERL, Ghostscript, Acroread, Xvile, ImageMagic, and the NCAR

plotting package were updated. StarOffice 5.1 was installed and setup which permits most documents and spreadsheets from Microsoft Word and Excel to be viewed, manipulated, and printed on the Sun workstations.

During the 1999 field deployment to Thule, Greenland a network of three Sun workstations was setup and configured for use in quality control, archiving, and mission planning activities. Also, a Sun Ultra 60 was installed in a field office in the home of Paul Lyon replacing a SGI Indigo2.

In support of the data process and archiving activities performed under Task 2 software was updated for writing CD-ROM's. Also, developed code to automate the process of verifying CDs and printing the liner sheet which is stored inside the jewel boxes where the CD-ROM's are stored.

Other Task 4 activities included the installation of a graphics tablet on a project PC under a DOS operating environment. Also code was developed to recover jpeg files from a corrupted Sony Digicam floppy.

Task 5 - Instrument Maintenance Engineering and Fabrication

Greenland and ALACE Mission Preparation

In January 99, preparation for both major deployments began with calibration checks of the distance measuring equipment used to calibrate both ATM systems. Comparisons between the older HP DME, the newer Pentex DME and the steel measuring tape were made, and results compared. The conclusion was to use the Pentex DME with frequent backup measurements with the steel tape. This conclusion was based on the ease of use of the Pentex in extreme conditions, and the averaging technique used in the Pentex measurement procedure. The commercial calibration of the Pentex was still valid for the 1999 missions. EG&G recommends that commercial calibration of the Pentex DME be procured prior to missions conducted in 2000. Commercial calibration will also bring the ATM calibration equipment into compliance with ISO 9001 level requirements.

In early April 99, modifications to the ATM software were made by the NASA engineer and EG&G personnel to provide an option to record lower resolution range data from higher altitudes. These modifications were designed to provide data useful in validating future ICESAT data. Laboratory and ground tests were conducted to ensure that the range data was recorded properly, and that the data could be processed. It was concluded that the software modifications were successful, and a version of ATM data collection program *atm312ps.exe* was provided. An improved rotating neutral density filter was developed prior to the Greenland 1999 mission and also used during the ALACE missions. The filter worked extremely well, and has a reduced chance of being damaged by either the laser or mechanical impact, as compared to the older rotating ND.

Ground Testing of the ATM-1 and ATM-2 systems began prior to aircraft installation in April 99. Both systems were found to be functional and ready for installation. Measurements of laser power were made to calculate laser eye safety distances to be included in the OSD.

Installation of the ATM-1 ATM-2 GPS and GPS/Steering systems on the NASA P3 aircraft began on April 20. Several ground tests of all aircraft systems was conducted between April 25-29, and preliminary checkout flights were conducted on April 29 and May 4. The data underwent preliminary processing and we concluded that the systems were ready to conduct the Greenland deployment.

The aircraft ATM-1, ATM-2, GPS, GPS/Steering systems were installed on the P3 twice during 1999, and onboard the NOAA Twin Otter once. The schedule for these installations was known in advance, so preparation for the installations reduced the problems encountered. The best preparation was the setup and ground testing of both ATM-1 and ATM-2 in the ground testing laboratory prior to the Greenland installation. This is a procedure we recommend for future Greenland missions.

EG&G recommends acquiring a back-up Continuum laser for ATM-2 system. The data from the Navassa Island mission was of high quality. The replacement of the Continuum with a TFR laser resulted in higher PMT gains being necessary, and introduction of noise in the ATM-2 measurements. EG&G recommends replacement of the present laser start pulse PMT detector, with the faster Hamamatsu PMT. In addition, a rotating ND method of varying start energy for calibration should be built into the detector to replace the current method of removing the fiber from the PMT face.

EG&G recommends development of alternative attitude reference systems to replace the Litton 92 for use on non-NASA aircraft, either a lower cost laser gyro system, or a GPS based attitude system. The benefit of a laser gyro system would be the use on multiple platforms not having GPS antennas. A GPS system may be the lowest cost provided GPS antennas can be installed on the aircraft the ATM is installed on. Borrowing the Litton 92 for ATM missions on non-NASA aircraft has the risk of breaking during the borrowing period, with the cost of repair being an unresolved issue.

Airborne Oceanographic Lidar (AOL) (Global Carbon Cycle)

Task 1 - Mission Planning and Execution and Sensor Operation and Calibration

The AOL laser fluorosensor and passive spectroradiometer suite of instruments participated in two major field deployments during the first option period of the contract. Both deployments were part of a joint NASA/NOAA project referred to as EstHab (Estuarine Habitat). The EstHab project, conducted in collaboration with the NOAA CSC (Coastal Services Center) in Charleston, SC, is designed to evaluate the suite of airborne active and passive ocean color sensors for meeting sampling requirements of state and federal agencies in coastal and estuarine watermasses. The EstHab project also permits NASA an opportunity to have access to a relatively low priced aircraft which is then available to conduct surveys of offshore pelagic watermasses required for the present thrust in Case 1 algorithm development and validation. A Memo-of-Understanding that formalizes the joint EstHab program was signed in 1999 by the directors of GSFC and CSC.

Planning for the EstHab missions was coordinated with scientists at CSC. Arrangements for surface truthing support for offshore waters were made by EG&G scientists with researchers from the NOAA National Marine Fisheries Survey and the Univ. of South Florida. Arrangements for surface truthing support in coastal and estuarine watermasses were coordinated by scientists from CSC. Whenever possible the coordination was made well in advance, however circumstances such as sampling following Hurricane Floyd required modifications of the schedule during the field deployment. The planning for the AOL missions also involved working with NASA mission managers to develop an Operational Safety Directive (OSD) which is required for all flight activities involving NASA civil service or contractor personnel. The OSD developed in preparation for the spring deployment was sufficiently structured to permit its application to the fall deployment. In this regard, EG&G recommends that NASA develop OSD's that can be used for longer periods of time when circumstances such as the aircraft and instrumentation remain essentially the same. This would reduce considerably the amount of redundant work involved with the advanced planning.

The first of the field deployments was initiated on March 1, 1999 and concluded on April 15, 1999. Approximately, 100 hours and 14 missions were flown on a NOAA Twin Otter aircraft during missions conducted in waters off NY, NJ, DE, MD, VA, SC, GA, FL, and MS. The initial investigations conducted with the AOL-3 sensor onboard the Twin Otter were to test the feasibility of making remote measurements of phytoplankton photosynthetic rate parameters using short pulse pump and probe (SP-P&P) methodology. The SP-P&P methodology was developed during rigorous laboratory investigations by Dr. Alex Chekalyuk⁶ in 1998 while an

⁶Dr Alex Chekalyuk is presently a National Research Council Senior Post Doc

EG&G employee. In the field demonstration conducted in March, 1999 EG&G and NASA engineers assisted Dr. Chekalyuk in integrating a second Nd:YAG laser into the AOL-3 sensor. The second laser was used as a pump laser during the investigation while the usual ATM-3 laser was used as a probe laser. A total of 5 missions were conducted over a 10-day period. Two of the missions were coordinated with the NOAA R/V Albatross in the Atlantic Ocean east of New York and Virginia. A Chelsea fast repetition rate (FRR) unit for measuring phytoplankton photosynthetic rate parameters was situated on the R/V Albatross, however it was later learned that the unit failed to record data during the cruise. The remaining three flights were conducted in the lower portion of the Chesapeake Bay and in coastal waters off the coast of Virginia. Results from the successful investigation of the airborne SP-P&P tests are discussed in Task 3. There was no room for the NASA ADAS sensor or the NOAA ASA sensor when the AOL-3 was in the SP-P&P configuration.

Following the SP-P&P flight the NASA ADAS and NOAA ASA sensors were installed on the NOAA Twin Otter aircraft. Five missions were conducted over Atlantic shelf, slope, and Gulf Stream waters east of the Virginia coast. After the completion of these mission the aircraft transited to Charleston where a mission was flown over the lower reaches of the Cooper and Ashley Rivers and within Charleston Harbor. A mission from Charleston was also coordinated with NOAA researchers operating from the R/V Blue Fin⁷. The aircraft then transited to Gulfport, MS from which a mission was staged in coordination with Naval Research Laboratory sampling efforts. Following the conclusion of this experiment, the aircraft sampled a cross-section of the Gulf of Mexico in route to St. Petersburg, FL. Two missions were staged from St. Petersburg in cooperation with Dr. Frank Muller-Karger⁸ who was conducting a cooperative experiment with Cuban scientists off the western coast of Florida on board the Cuban R/V Hercules. One additional mission was flown over the Pacific Reef in the Florida Keys to permit evaluation of the present status of the AOL-3 sensor for acquiring useful fluorescence measurements over coral reefs. The instrumentation was off loaded and driven back to WFF in a rental truck.

The fall deployment began with the installation of the AOL-3 suite of airborne active and passive sensors in the NOAA Twin Otter on October 1. A total of 95 hours on 16 missions were flown during the fall EstHab campaign. The initial five initial missions were conducted over Atlantic shelf, slope, and Gulf Stream waters east of the Virginia coast. Two missions were conducted over the Pamlico Sound and adjacent waters to assess the effects of runoff from Hurricane Floyd. These post hurricane missions were about 7 hours in duration and required a refueling stop in Manteo, NC. This was followed by three missions with the AOL-3 in the SP-P&P configuration conducted over the lower Chesapeake Bay and Atlantic Ocean east of Virginia. The final SP-P&P mission was flown from WFF across Atlantic shelf, slope, and Gulf Stream waters. Following the SP-P&P missions the AOL-3 was configured in the conventional fluorosensing

⁷Skidaway Institute of Oceanography

⁸Univ. of South Florida

mode of operation and the NASA ADAS and NOAA ASA sensors were added. An additional post Hurricane Floyd mission over the Pamlico Sound and surrounding waters was conducted. After the conclusion of this mission the aircraft ferried to St. Petersburg, FL.

The missions flown out of St. Petersburg, FL were designed to assess the potential of the AOL-3 suite of active and passive airborne sensors to detect and measure harmful algal blooms which are common along the Florida Gulf coast during the fall. Three missions were flown in coordination with the University of South Florida. However, high winds prevented the R/V Suncoaster from conducting most of the planned sampling. The high winds from the northeast continued for several more days. It was then decided to postpone the harmful algal bloom investigation until late November.

Two final missions designed to investigate harmful algal blooms were conducted during the final week of November. The first of these was flown over coastal waters and embayments between Panama City, FL and Pensacola, FL. The total flight time was about 6 hours and required a refueling stop in Pensacola. The second of these missions was flown over coastal waters southwest of Sarasota using lines previously occupied during the experiment coordinated with the University of South Florida earlier in November. The sensors were then off loaded at the NOAA Aircraft Operations Center in Tampa, FL and were then hauled back to WFF in a rental truck.

SLF Planning and Mission Execution

The Shipboard Laser Fluorometer (SLF) was originally developed by the EG&G engineering staff under the previous contract. The SLF is a modified Oriel IV spectrometer, with a fiber probe designed to couple transmitted laser energy through a center fiber bundle surrounded by a concentric bundle of fibers which carry the induced fluorescence to the Oriel spectrometer. The fiber probe gathers the fluorescence of seawater as it passes through a sampling chamber which is connected to a standard shipboard seawater flow through system. The SLF system can acquire high resolution spectra of laser induced fluorescence continually during a research vessel cruise. The instrument is essentially automated, requiring only a technician to restart the data collection program daily and to occasionally monitor the status of the sensor. The SLF system takes up less than 2 square feet of bench space within a shipboard laboratory.

The SLF was modified during 1999 to permit the use of two different laser wavelengths (355 nm and 532 nm) to acquire separate laser induced fluorescence spectra. As with the AOL, the 532 nm radiation induces chlorophyll and phycoerythrin fluorescence and water Raman backscatter at 650 nm while the 355 nm radiation induces fluorescence from chromophoric dissolved organic matter and water Raman backscatter at 404 nm.

Since its introduction in 1997, the SLF has been under considerable demand within the marine biological research community. The sensor was deployed on numerous cruises during the final year of the preceding contract. EG&G recommends continuation of the following procedure in

connection with future deployments of the SLF.

Recommended Procedures for SLF Deployment	
1	Laboratory check-out of the SLF at WFF prior to shipping
2	Ship the SLF to the research vessel dock
3	Send an EG&G engineer to the location of the research vessel
4	Install of the SLF in the wet laboratory of the research vessel (EG&G engineer)
5	Train a ship technician in the operation of the SLF (EG&G engineer)
6	Arranging for return shipment of the SLF to WFF after the cruise (EG&G engineer)

The SLF was utilized on six separate field deployments during 1999. The table below provides the time period, research vessel name, location of the cruise, and duration in days.

List of SLF Cruises During 1999			
Date	Ship	Location	Duration
Jan 99	Revelle	Pacific Ocean	21 days
Mar 99	Albatross	Mid Atlantic Bight	10 days
Apr 99	Suncoaster	Gulf of Mexico	3 days
Jul 99	Hatteras	Gulf of Maine	10 days
Oct 99	Melville	Pacific Ocean	21 days
Nov 99	Suncoaster	Gulf of Mexico	3 days

The SLF operated in three different modes during cruises in 1999, depending on the expected results, and the level of development of the SLF at the time of the cruise. Cruises early in 1999 either used a single laser wavelength excitation (532 nm), or dual (non-separated) laser wavelength excitation (355 and 532 nm). The last two cruises in 1999 used a newly developed laser wavelength separator to acquire separate 355 and 532 nm laser excited fluorescence spectra.

The SLF collected data successfully on portions of all cruises, with the experience gained during earlier cruises resulting in improvements to the system which increased the data collection rate later in 1999. During the Pre-Launch MODIS cruise on the R/V Melville the SLF collected good data during all periods it was operated (19 days of 21 day cruise).

AERONET CIMEL CSPOT Sensor Operation

EG&G is providing support for a newly installed Cimel Sun Photometer CSPOT sensor at WFF. The CSPOT, installed on a tower behind the mobile radar support facility, is an automatic sun-sky scanning spectral radiometer provided by Brent Holben NASA's GSFC code 923. Support for the CSPOT includes the occasional tasks of setting computer and transmitter system clock, aligning the sensor, and monitoring the down-linked data from the GSFC AERONET website to ensure the WFF CSPOT is functional.

Task 2 - Data Processing Cataloguing and Archiving

Global Carbon Cycle (C00) - Between 3/8/99 and 11/29/99 there were nine Pump & Probe flights and 30 EstHab flights in addition to plus several checkout flights. All the data from the AOL, ADAS, CDAS, and SAS sensors were transferred from removable hard drives to CD-ROM disks for permanent storage along with NOAA satellite weather images secured from the Internet on all of the days when there are AOL flights. Two copies of the raw data were made with one copy shipped to the Gaithersburg office for secure storage. The other copy remains at Wallops for use in processing and analytical activities.

During the initial 8 months of the present contract we acquired raw SeaWiFS LAC imagery directly from the downlink site at N-161 through a fiber-optic cable. This procedure was time consuming often requiring interaction between EG&G technicians and technicians in N-161. This policy was internally reviewed by the EG&G scientific staff. They recommended discontinuance of the direct acquisition from N-161, but instead to acquire the imagery over the internet from either the SeaWiFS project office of the DAAC at GSFC Greenbelt. NASA adopted the recommendation.

Task 3 - Data Analysis Interpretation and Reporting and Laboratory Analytical Support

Results were reported in seven refereed journal articles in which one or more EG&G scientific or engineering personnel was a contributing coauthor. The majority of these publications were submitted during the latter portion the year, thus the actual publication will appear in 2000.

Hoge, F. E., C. Wayne Wright, Paul E. Lyon, Robert N. Swift, and James K. Yungel, Inherent optical properties imagery of the western North Atlantic Ocean: Horizontal spatial variability of the upper mixed layer, submitted to *JGR*, 2000. This paper is the first published linear inversion of a SeaWiFS image. The phytoplankton and CDOM ditritus IOP retrievals are supported by both contemporaneous laser-induced fluorescence data acquired with the AOL and IOP's retrieved from the ADAS spectra. The total constituent backscattering IOP recovery from the SeaWiFS imagery is validated by similar recovery from the ADAS spectra.

Hoge, F. E., C. Wayne Wright, Paul E. Lyon, Robert N. Swift, and James K. Yungel, Satellite retrieval of inherent optical properties by radiance model inversion, Feasibility of the required

rigorous atmospheric correction. *Applied Optics*, submitted, 2000. This paper demonstrates that airborne water leaving radiance can be used to provide atmospheric correction for SeaWiFS imagery.

Hoge, F.E., C. Wayne Wright, Paul E. Lyon, Robert N. Swift, James K. Yungel, Satellite Retrieval of the Absorption Coefficient of Phytoplankton Phycoerythrin Pigment: Theory and Feasibility Status, *Applied Optics*, In Press, 2000. This paper demonstrates that phycoerythrin absorption can be retrieved from airborne ocean radiance spectra.

Hoge, Frank E. and Paul E. Lyon, "Spectral Parameters of Inherent Optical Property Models: Feasibility of Satellite Retrieval by Matrix Inversion of an Oceanic Radiance Model", *Applied Optics* 38, 1657-1662 (1999). The Parameters paper showed a technique to retrieve IOP spectral model parameters simultaneously with the IOP's during the inversion of the semi-analytic radiance model. The paper demonstrated the technique where our standard inversion is augmented with a Taylor series expansion of one of the IOP spectral models and 4 bands are used in the inversion instead of 3. We found that the initial guess for what the parameter should be is important and needs to be close to the real parameter value. The paper investigated the retrieval of parameters associated with the 3 IOP spectral models for phytoplankton absorption, CDOM absorption and Total Constituent Backscattering.

Hoge, Frank E., C. Wayne Wright, Paul E. Lyon, Robert N. Swift, James K. Yungel, Satellite retrieval of inherent optical properties by inversion of an oceanic radiance model: A preliminary algorithm, *Applied Optics* 38, 495-504 (1999). This paper describes results of applying a semi-analytic inversion technique to airborne radiance spectral data.

Chekalyuk, A.M., F.E. Hoge, C.Wayne Wright, R.N. Swift, and J.K. Yungel, Short-pulse pump-and-probe protocol for airborne LIDAR assessment of photosynthetic activity, Submitted to Photosynthesis Research (October, 1999). This paper describes the theoretical development of short-pulse pump-and-probe (SP-P&P) protocol and shows laboratory results that are in good agreement with theoretical P&P protocol.

Chekalyuk, A.M., F.E. Hoge, C.Wayne Wright, R.N. Swift, and J.K. Yungel, Airborne test of LIDAR pump-and-probe technique for measurements of phytoplankton photochemical parameters, Submitted to Photosynthesis Research (December, 1999). This paper describes the airborne application of short-pulse pump-and-probe (SP-P&P) protocol and shows airborne results that are in good agreement with laboratory P&P results and theoretical P&P protocol.

Instrument Calibration.

The NASA AOL calibration facility was used to calibrate the NASA ADAS instrument on 3 separate occasions in 1999, and once to calibrate the SLF. The ADAS calibrations were used to process the data acquired during the ESTHAB missions. The ADAS results from the April 1999 calibration matched the results from 1998 to < 1%. We conclude, based on the calibration

results, that the ADAS instrument has been very stable over the past year. The SLF had not been calibrated previously, so the initial calibration will provides a benchmark on understanding sensor stability following future instrument calibrations. EG&G recommends periodic calibration of both the SLF and ADAS instruments. EG&G also recommends procurement of a new 200W standard calibration lamp to replace the present lamp during year 2000.

Airborne Data Processing and Analysis

All of the data acquired during the spring EstHab missions was processed through software developed during the previous contract period. The processed data was graphed to permit interpretation. All of the processed data was placed on the Observational Science Branch public ftp site for transfer to CSC. The data was then analyzed to determine which data sets were suitable for further analysis in the linear model inversion effort described later in this section. Criterion for selection were (1) clear sky as determined from graphs of the up-looking CDAS irradiance data and examination of NOAA weather satellite images; (2) variability in chlorophyll and phycoerythrin pigment concentrations; and (3) non-coherence between CDOM, chlorophyll, and phycoerythrin. Finally, these data sets were processed through active-passive correlation spectroscopy (APCS) software to reveal whether the data was of sufficient quality to warrant further analytical effort using linear matrix inversion methods. Previous experience with APCS methods have shown that if high correlation values between the laser-induced fluorescence measurements and corresponding radiance-ratio or 3-band curvature retrievals of the chlorophyll, phycoerythrin, or CDOM parameters were found, then the data set was sufficiently uncorrupted to make the application of more sophisticated (and more time consuming) methods worthwhile.

The data acquired during the fall EstHab missions has only been partially analyzed. The GPS "GGA" ascii data stream was found to be corrupt as was the sea surface temperature from the auxiliary Heimann infrared radiometer. The data was found to be recoverable, but two new software programs had to be developed. The data was initially processed through *fix_garman* to fix the errant positioning data and through *concens_fl99* to correct the bad temperature data. At this point, the fall EstHab data needs to be processed through the usual AOL data processing software and be graphed, posted on the public ftp site, and analyzed as described in the preceding paragraph. We project that the data will be processed and given preliminary analysis by the end of January, 2000.

Modeling and Linear Model Inversion Investigations

An attempt was made to formulate the radiative transfer equations for the atmosphere in a manner similar to J. R. V. Zaneveld [1982] partitioning of the radiative transfer equations in the water. If successful, the exact radiative transfer equations could be linearized, and thus "inverted" to obtain characteristics of the aerosols present in the atmosphere. This information could be used to correct satellite data more directly. An extensive data set of 4 PI steradian radiance measurements from Scripps Institute was studied to see if certain parameters in the Zaneveld partitioning could be modeled. It was found that the important "shape factors" covered

too wide a range to allow the atmospheric exact radiative transfer equations to be partitioned in Zaneveld's form.

In order to apply the semi-analytic inversion method to satellite data, the satellite data must have the atmospheric radiances removed. Once we can reliably retrieve remote sensing reflectances from satellite ocean radiance imagery, we should have the same success inverting the satellite data that we have had inverting airborne ADAS data. A considerable effort during the past year has been spent getting SeaWiFS satellite data to match with ADAS data taken on the same day as the SeaWiFS image. To accomplish this, the standard SeaDAS processing code had to be rewritten in sections to alter the atmospheric processing steps and to output the final data in units comparable to the ADAS data. Once the at-satellite digital counts were calibrated and the Rayleigh radiance removed from each channel, the data could be used in conjunction with the ADAS data derive methods to remove the aerosol radiance from each channel. The resulting atmospherically corrected remote sensing reflectance images should match the airborne ADAS data, and thus be invertible to obtain phytoplankton absorption, CDOM absorption, and Total Constituent Backscattering over the entire satellite image and globally for global data sets. Some success has been realized in purely empirical methods which demonstrated that the information needed to atmospherically correct the satellite data is contained within the satellite data set. Recent work has yielded more promising methods that are based on the physics of the photon interactions with aerosols and molecules which should lead to more general atmospheric correction methods. More concurrent data is needed from both ADAS and SeaWiFS to increase our knowledge of the different aerosol spectral shapes for different combinations of aerosols. Most ADAS data is taken in the Mid Atlantic Bight, so it typically contains the diverse water mass types associated with that region, which is important. The atmospheric conditions may be some of the most challenging in the world since the prevailing winds bring terrestrial aerosols and urban pollutants into the area. We feel that if we are successful in developing a correction method that works in the MAB, it has a good chance of working in many other portions of the world's oceans. With the successful launch of MODIS, more data will be available to test our methods. MODIS data will have additional infrared wavelength bands to use in our studies.

Results from SLF Investigations

The SLF data analysis is evolving as each of the 3 modes of operation mentioned earlier were employed during the various cruises in 1999 and in response to the instrument improvements that were incorporated as efforts were made to improve SLF robustness after each cruise. Some problems were experienced with the SLF during some cruises early in the year. Specifically the fluorescence spectra on some cruise tracks were of such poor quality as to make interpretation of the results impossible. However, even these cruises had cruise tracks that were of high quality. Determining the cause of the bad data has been difficult. Since the SLF is almost autonomous, no one has observed the misbehavior of the SLF within the shipboard environment. The current hypothesis for explaining the bad data is that it is due to variations in water flow in the shipboard sampling system. It is worth noting that improvements in the design of the SLF sampling chamber seem to have improved the success rate for SLF data for the later 1999 cruises. The

auxiliary measurements of sea surface temperature and scatter have also been less reliable than desired. Both units fail to send proper signals at various times during the cruises. EG&G recommends replacing both auxiliary sensors in 2000.

The high quality data acquired during the SLF cruises shows great promise for improving the ability to measure phycoerythrin and chlorophyll. The high signal to noise ratio allows measurements of extremely small concentrations of pigments. The SLF also facilitates differentiation between Type I and Type II phycoerythrin, without the need for pigment extractions. An example of the capability to recover the two phycoerythrin types is provided in Figure 2 (top) where spectra containing each of the types were recovered respectively at locations "A" and "B" within the Gulf of Maine at the locations marked in Figure 2 (bottom). The separate wavelength laser excitation mode was used during the October Pre-Launch MODIS cruise for the first time. The SLF data processed so far suggests that the measurement of phycocyanin fluorescence is possible. We recommend continuing improvement of the SLF in order to validate both aircraft and satellite sensors.

Pump and Probe results

The data from the March 1999 SP-P&P flights was processed and the results predicted from the 1998 laboratory experiments were observed in the aircraft data. A paper describing the results has been written and submitted to *Photosynthesis Research*. The results from the March missions were used to develop hardware and software improvements to the AOL-3 system to enhance the ability of the sensor to make SP-P&P measurements by eliminating the need to repeat flight line at varying laser power settings. These improvements were tested in flights in October. The data from the October flights will be processed early in the next option period in the contract.

Task 4 - Network Development and Maintenance

See the Task 4 discussion for the ATM sensor (above). Tasks described in that section apply to the AOL sensor support in this section.

Task 5 - Instrument Maintenance Engineering and Fabrication

Sensor Modifications

The AOL-3 instrument was modified several times during 1999, in order to facilitate an evaluation of the potential for acquiring photosynthetic rate parameters from an aircraft at an altitude of 150 m using SP-P&P methodology developed in the laboratory during the preceding contract. The modification for the March flights included the addition of a second laser transmitter which functioned as the pump pulse during the investigation. Careful attention was afforded the alignment and timing of the pump and probe pulses which must be directed into essentially the same footprint with a separation between the pump and probe pulse optimally set

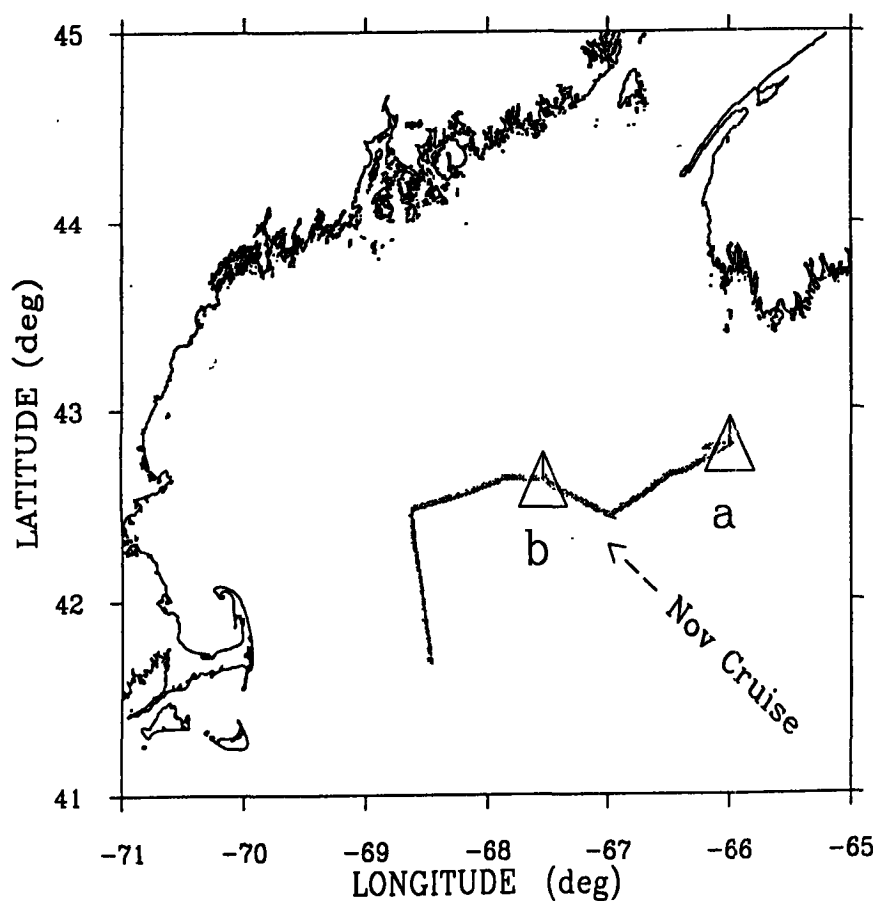
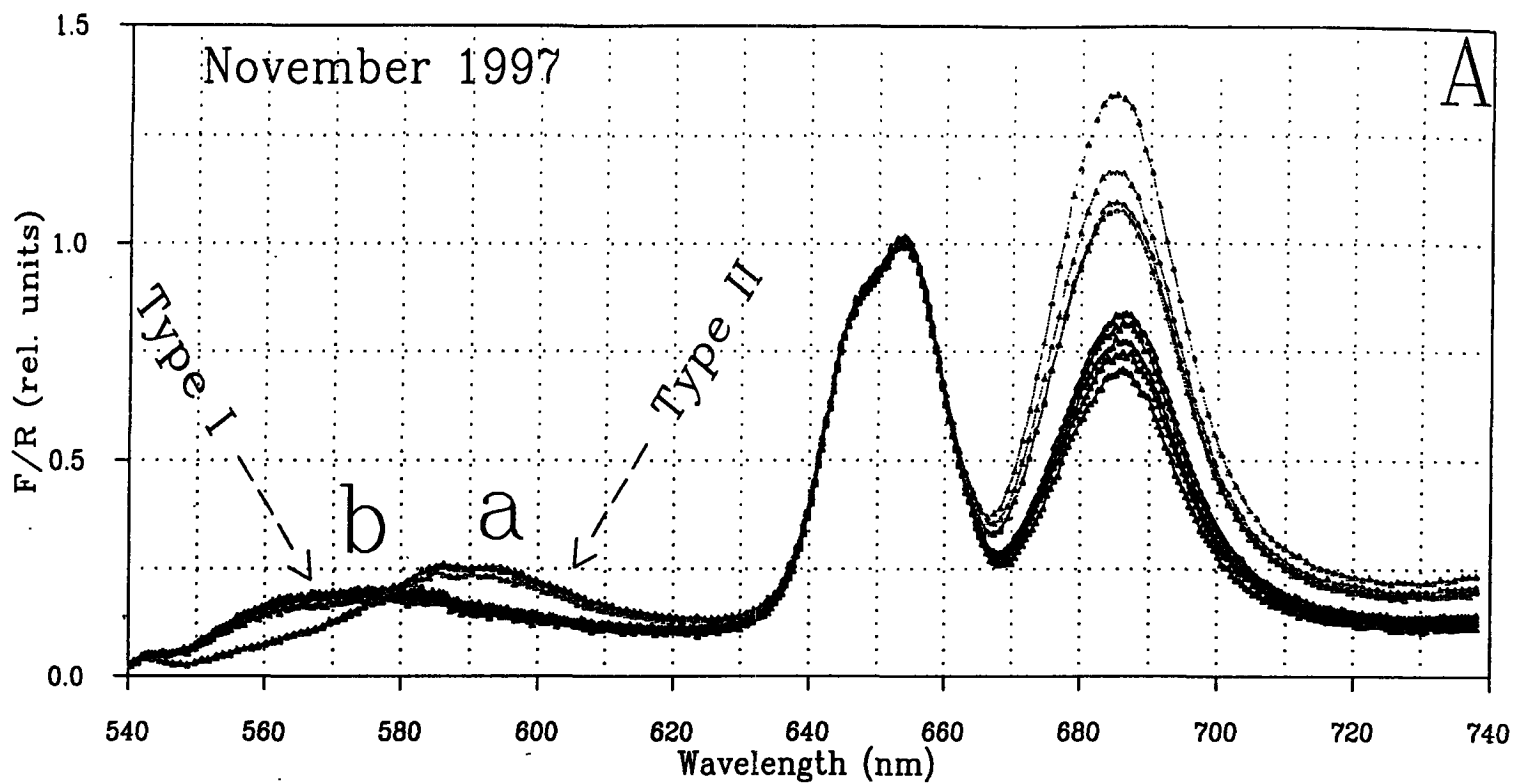


Figure 2 (top) Spectra acquired with the Shipboard Laser Fluorometer during a cruise in the Gulf of Maine in November, 1997. Shown are Type I and Type II phycoerythrin peaks. The spectra were gathered at locations marked (a) and (b), respectively in Figure 2 (bottom).

for 30 microseconds. Other modifications included start pulse fiber mods, ground test mirror construction, and mounting of optical lenses to control the size of the pump laser spot.

The AOL-3 instrument currently has 3 Big Sky lasers available for use as transmitters. Currently one power supply and one laser head are experiencing problems. EG&G recommends return of these units for repair as soon as possible.

Other Instrument Maintenance and Modification Activities

The AOL-3 Twin Otter mounting structure was rebuilt before the September ESTHAB flights to improve the supports for the ADAS and SAS down-looking sensors. The fabrication of a smaller ADAS down-looking sensor was begun during 1999. The prototype unit of this sensor has been developed by a NASA engineer. This miniturized ADAS sensor will be tested early in the next option period.

The SLF was modified several times to correct suspected sample chamber flow problems. The SLF was also modified to allow installation of a laser wavelength separator under SLF control.

NASA engineers developed a prototype airborne laser bathymetric system to test the feasibility of utilizing a short (~1 ns), low power (0.2 mJoules), high prf (5KHz) pulsed Nd:YAG laser to acquire shallow water bathymetric data. The Experimental Advanced Airborne Research Lidar (EAARL) was constructed in January, 1999 and was installed on a NOAA Twin Otter in Tampa, FL and tested on missions flown out of Tampa on February 9 and 10. The prototype EAARL sensor was also flown over Carysfort Reef in the Florida Keys on February 11. Following that field test, the EAARL was ferried along with the aircraft to WFF where a brief mission was conducted over Chincoteague Bay and nearby forested areas prior to removing the sensor. The evaluation of the data from the sensor indicates strong promise that the instrument will be capable of measuring coral reefs and in doing shallow water bathymetry in clear bodies of water. Although the operation of the EAARL and the data analysis from the sensor have thus far been done by a NASA civil service employee, it is expected that EG&G engineers and analysts will work with the EAARL and the data from the sensor after the implementation of the instrument in ~June, 2000.

Scanning Radar Altimeter (ATM)

Task 1 - Mission Planning and Execution and Sensor Operation and Calibration

No activity during reporting period.

Task 2 - Data Processing Cataloguing and Archiving

No activity during reporting period.

Task 3 - Data Analysis Interpretation and Reporting and Laboratory Analytical Support

No activity during reporting period.

Task 4 - Network Development and Maintenance

No activity during reporting period.

Task 5 - Instrument Maintenance Engineering and Fabrication

Several airborne radar altimeters and scatterometers were maintained, repaired, and refurbished under Task 5. These are individually discussed below.

DLS-Long-EZ

We have had good results from 4 field programs in which the DLS has participated. Scatterometer measurements have been made over a wide range of wave conditions, with wave heights ranging from 0-4 meters and wind speeds of 0-20 meters/sec. Data has looked good for at least the first 12 of 20 flights from the flown during the November deployment to Duck, NC. Future plans include a possible series of flights out of Monterrey, CA during summer, 2000. The PI is also considering developing another version of the DLS at Ku band (13.9Ghz), to be built using a flat panel phased array antenna.

Radar Ocean Wave Spectrometer (ROWS)

ROWS has not flown much this past year, but has provided good data since the last modifications. There are no specific plans for further upgrades at this time. The ROWS may participate in Bermuda-Delaware Bay flight(s) during summer, 2000.

Scanning Radar Altimeter (SRA)

The SRA was flown successfully in 8 flights through hurricanes this year. See Table 1. The first flight used the new roll compensated GPS antenna which worked successfully throughout, until being struck by lightning on the last flight of the hurricane season, which disabled it. The repackaging of the transmitter power supplies worked out well. There were some antenna related problems with the GPS systems, both the ground and airborne units. Another problem requiring some checking, is the intermittent loss of the transmitter-detected pulse during some flights, and a final failure when the PI tried to perform a post-cal on the ground at the end of the final hurricane flight. Otherwise we think the system performed pretty well. We are proceeding to set up the technique for ground testing to check out the transmitter-detected pulse problem once the sensor has returned to WFF. We have already checked the cables associated with the detector and found one SMA connector quite loose, possibly the cause of the intermittent and then full failure. Future plans call for supporting Rainfall Measurements on the NOAA P-3 and also more storm surge mapping for northeasters following installation in one of the NOAA Twin Otter aircraft.

Some minor problems to be resolved with the SRA sensor. These are:

- 1.) Bad ethernet card, presently preventing system operation.
- 2.) Intermittent transmitter-detector pulses.
- 3.) Missing every 8th or 10th transmitter pulse.

Table 1	
SRA Hurricane Flights in 1999	
# of Flights	Hurricane
1	Brett
1	Dennis
3	Floyd
2	Irene
1	Lenny

Bimonthly Progress Reports for Contract NAS5-99094

Glossary of Acronyms

ADAS	Airborne Diode Array Spectrometer
AGC	Automated Gain Control
ALACE	Airborne Lidar Assessment of Coastal Erosion (joint NASA/NOAA/USGS program to measure changes in coastal morphology)
AOL-3	Airborne Oceanographic Lidar (version 3 put into service in March, 1998)
AIM	Arctic Ice Mapping (NASA program to measure the mass balance of arctic ice sheets such as the massive ice sheet covering Greenland)
ASA	Airborne SeaWiFS Simulator
ATM	Airborne Topographic Mapper (Versions 1 and 2 are both in current use)
CDAS	Cosine Diode Array Spectrometer
CDOM	Chromophoric dissolved organic carbon
CIMEL	Automated Sun-tracking photometer
CCG	USGS Center for Coastal Geology (St. Petersburg, FL)
CSC	NOAA Coastal Services Center (Charleston, SC)
DAAC	Distributed Active Archive Center
DEM	digital elevation model
DLS	Down-Looking Scatterometer
EAARL	Experimental Advanced Airborne Research Lidar sensor
EstHab99	Estuarine Habitat Project - joint NOAA/NASA initiative to study coastal waters and to evaluate remote sensor performance in these environments.
GAC	Global Area Coverage (ocean color satellite imagery)
GLAS	Geodetic Laser Altimeter
GPS	Global Positioning System

GSFC	Goddard Space Flight Center
ICESat	Ice Cloud and Land Elevation Satellite
IOP's	Oceanic Inherent Optical Properties (chl absorption, CDOM absorption and total constituent backscatter)
JGOFS	Joint Global Ocean Flux Studies
IR	Infrared
LAC	Local Area Coverage (ocean color satellite imagery)
OSD	Operations and Safety Directive (required by GSFC Safety for all airborne programs)
NOAA	National Ocean and Atmospheric Administration
NRC	National Research Council (personnel)
PARCA	NASA Program for Arctic Regional Climate Assessment
P&P	Pump and Probe (lidar methodology for measuring photo synthetic rate parameters)
ROWS	Radar Ocean Wave Scatterometer
R/V	Research Vessel
SAS	SeaWiFS Airborne Simulator (NOAA CSC sensor)
SeaWiFS	Sea-viewing Wide Field-of-View Sensor (satellite ocean color scanner)
SeaDAS	SeaWiFS Data Analysis System (processing and display software)
SLF	Shipboard Laser Fluorometer
SP-P&P	short pulse Pump and Probe
SST	Sea Surface Temperature (captured from the Heimann IR Radiometer)
USGS	U.S. Geological Survey
UV	Ultraviolet

WFF Wallops Flight Facility

Computer Programs

gitar ATM project software for phase code tracking differential GPS data

gypsy Jet Propulsion Laboratory software for positioning a fixed GPS receiver

mplot AOL project plotting software to produce multiple plots per page

72114/45

Bimonthly Contractor Report for NAS5-99094

Period Covered: April, 2001 though May, 2001

General Discussion

Contract NAS5-99094 was initiated on December 1, 1998. The first 1-year option, consisting of Tasks 1 - 5, was completed on November 30, 1999. A second 1-year option, consisting of Tasks 6 - 10, was initiated on December 1, 1999. The third 1-year option, consisting of Tasks 11 - 15, was initiated on December 1, 2000. Tasks 11 - 15 cover specific activities in support of 3 major sensor programs, each with a separate NASA Principal Investigator (PI). Accordingly, the bimonthly narrative is organized such that each of the programs are discussed separately with individual task activities presented within each of the programs. Acronyms are used throughout the report to keep the writing succinct. An attached glossary contains definitions for these acronyms.

Airborne Oceanographic Lidar (AOL) (Global Carbon Cycle)

Task 11 - Mission Planning and Execution and Sensor Operation and Calibration

Most of the planning for spring 2001 Estuarine Habitat (EstHab01) missions was conducted during the previous reporting period. However, specific plans for conducting missions over the Albemarle and Pamlico Sounds as well as a mission over Charlotte Harbor (FL) were developed in early April. The Albemarle and Pamlico Sounds surveys were conducted in collaboration with Dr. Pat Tester of the NOAA Marine Laboratory in Beaufort, NC. The mission over Charlotte Harbor (FL) was conducted in collaboration with Kellie Dixon of Mote Marine Laboratory in St. Petersburg, FL. In addition plans were formulated for a mission to conduct a diel experiment in the MAB in collaboration with Dr. Hugh MacIntyre of the U. of MD Horn Point Laboratory. Tables 1A and 1B provide a listing of the individual missions flown during the EstHab01 campaign along with information of flight duration and staging airport.

Missions were flown over New Jersey coastal and lagoon waters on March 14 and 19 and on April 5. These were coordinated with NJ Dept. of Water Resources who sampled at several locations during the missions. The March missions were discussed in the previous bimonthly report. A survey of the lower Delaware Bay was included in the April 5 mission.

A number of the missions were designed to provide validation for the SeaWiFS and MODIS satellites. These missions were flown on clear days. Most of these missions were flown to the Gulf Stream on flights conducted in the MAB southeast of WFF. One of the satellite validation missions was conducted from Beaufort, NC as part of the field studies centered on the Albemarle and Pamlico Sounds.

The Shipboard Laser Fluorometer (SLF) was operated on the R/V Parker on one mission during the reporting period as well as on the Old Dominion University research vessel during a survey of the lower Chesapeake Bay.

Following the conclusion of the survey of Charlotte Harbor, the AOL instrumentation suite was removed from the Twin Otter at the NOAA Aircraft Operations Center in Tampa, FL. The instrumentation was transported to WFF via a rental truck.

Task 12 - Data Processing Cataloging and Archiving

The data from the missions flown with the AOL suite of sensors was saved to CDROMS and placed into the project's archiving system. Several of the missions were distributed to collaborators via the AOL website at <http://aol.wff.nasa.gov> where plots of the measured parameters can be seen or from which the data can be ftp'ed in ascii format.

Task 13 - Data Analysis Interpretation and Reporting and Laboratory Analytical Support

Data processing from the fall, 2001 EstHab01 missions was initiated and the data from several of the most critical missions conducted over the NJ ocean and coastal waters was distributed to collaborators at the NOAA Coastal Services Center and the NJ Dept. of Water Resources. The processing and distribution of the remaining data sets will continue into the next reporting period.

Post Mission calibrations were performed during April, 2001 on the ADAS, CDAS in the WFF calibration facility following the Spring, 2001 missions. These calibrations will provide stability checks on the new ADAS telescope, and the new CDAS diffuser. In addition the new OCLI Micropac was calibrated in order to determine its stability during the spring ESTHAB missions.

Data from AOL3 ESTHAB missions from Spring, 2001 was processed as quickly as practical. Data from most missions was placed in ftp and web sites for distribution. SEAWiFS images were also placed in the web site to assist in selecting data for advanced processing. Processing is continuing to merge the passive data with the active laser data, and to evaluate the new MicroPak data. Preliminary comparison of ground truthing from samples taken during the New Jersey coastal missions showed very good correlations between the airborne laser data and surface samples over a wide area of coastal NJ.

The WFF Aeronet CSPOT sensor was damaged during an ice storm in late December. Email with GSFC discussing setting up a new unit during late June was exchanged.

Discussions with Frank Hoge about the feasibility of detection of sulfate and carbonate Raman spectra of sea water occurred during the March time frame. Web and library searches of the topic were requested. A quick preliminary experiment using the NASA SLF equipment to measure the bending mode of the water Raman yielded negative results (perhaps due to poor optical filtering

Table 1A. Takeoff and Landing Times/Sites and Objectives for EstHab Spring01

03/02/01 to 04/04/01

Date	Site	Take Off	Site	Land	Dur.	Objective	SC
03/02/01	WFF	13:15	WFF	15:25	2.2	AOL Instrument Check	Yes
03/07/01	WFF	18:30	WFF	20:15	1.8	Instrument Check Pump and Probe	Yes
03/08/01	WFF	11:05	WFF	13:40	2.6	SeaWiFS	Yes
03/09/01	WFF	09:00	WFF	11:50	2.8	Chesapeake Bay	Yes
03/12/01	WFF	09:45	WFF	12:50	3.1	SeaWiFS	Yes
03/14/01	WFF Atl. City, NJ	08:30	Atl. City, NJ	10:50	2.4	EstHab	Yes
		13:50	WFF	14:45	1.0	EstHab	Yes
					3.4		
03/18/01	WFF	18:15	WFF	21:05	2.9	Pump and Probe	Yes
03/19/01	WFF Atl. City NJ Atl. City, NJ	09:15	Atl. City, NJ	10:05	0.9	EstHab	Yes
		10:45	Atl. City, NJ	13:55	3.2	EstHab	Yes
		14:40	WFF	16:45	2.1 6.2	Est Hab	Yes
03/20/01	WFF	18:30	WFF	20:45	2.3	Pump and Probe	Yes
03/23/01	WFF Easton MD Easton MD WFF	05:15	Easton, MD	08:10	2.9	Pump and Probe	Yes
		09:15	Easton, MD	10:40	1.5	Pump and Probe	Yes
		12:00	WFF	15:45	3.8	Pump and Probe	Yes
		16:45	WFF	19:05	2.4 10.6	Pump and Probe	Yes
03/28/01	WFF	13:30	WFF	16:55	3.5	SeaWiFS	Yes
03/31/01	WFF	18:20	WFF	21:25	3.1	Pump and Probe	Yes
04/03/01	WFF	09:55	WFF	12:50	2.9	EstHab	Yes
04/04/01	WFF	15:30	WFF	17:25	2.0	Pump and Probe	Yes
	WFF	19:20	WFF	22:25	3.1 5.1	Pump and Probe	Yes

SC = Successful

Takeoff and landing times are EST (prior to 04/01/01) and EDT (thereafter)

Dur = Duration in tenths of an hour

NA = Not Applicable

Total Flight Hours on each day shown in **bold**

Table 1B. Takeoff and Landing Times/Sites and Objectives for EstHab Spring01

04/05/01 to 04/16/01

Date	Site	Take Off	Site	Land	Dur.	Objective	SC
04/05/01	WFF	11:05	Atl. City, NJ	14:35	3.5	EstHab	Yes
04/05/01	Atl. City, NJ	15:10	WFF	18:15	3.1	EstHab	Yes
					6.6		
04/09/01	WFF	09:40	WFF	12:50	3.2	EstHab	Yes
04/09/01	WFF	19:20	Beaufort, NC	23:00	3.4	Pump and Probe	Yes
					6.6		
04/10/01	Beaufort, NC	12:05	Ocracoke, NC	13:10	1.1	EstHab	Yes
		15:30	Beaufort, NC	17:55	2.4	Pump and Probe	Yes
04/10/01	Ocracoke				3.5		
04/11/01	Beaufort	09:30	Beaufort	12:55	3.5	EstHab	Yes
04/11/01	Beaufort	13:40	Beaufort	16:05	2.5	EstHab	Yes
04/11/01	Beaufort	19:30	Beaufort	21:00	1.5	Pump and Probe	Yes
					7.5		
04/12/01	Beaufort	09:40	Manteo, NC	11:35	2.9	EstHab	Yes
04/12/01	Manteo	12:10	Beaufort	13:15	1.1	EstHab	Yes
04/12/01	Beaufort	15:05	Tampa, FL	19:05	4.0	Transit	N/A
					8.0		
04/14/01	Tampa, FL	09:20	Tampa, FL	12:35	3.3	EstHab	Yes
04/15/01	Tampa, FL	09:45	Marathon, FL	12:55	3.2	EstHab	Yes
04/15/01	Marathon	13:50	Marathon	16:10	2.4	EstHab	Yes
	Marathon	19:40	Tampa, FL	22:55	3.3	EstHab	Yes
					8.9		

SC = Successful

Takeoff and landing times are EST (prior to 04/01/01) and EDT (thereafter)

Dur = Duration in tenths of an hour

NA = Not Applicable

Total Flight Hours on each day shown in **bold**

of the laser frequency), and a holographic notch filter was ordered to correct that problem.

Time has also been spent getting more global SeaWiFS data processed to derive IOP's that will be used to create global maps of the absorption of chlorophyll, dissolved organic matter, and the backscattering coefficient. These IOP's will also be used to generate maps of global particulate organic carbon and dissolved organic carbon estimates. More computer hardware was purchased and software installed to process the global data more quickly and to store the large quantities of data. Carbon products have been compared to shipboard extractions to help quantify the errors in the carbon algorithms.

The development of software to view the global IOP and carbon image files continued during the reporting period. This software allows daily images to be looped or stepped through one at a time to allow for close study of the dynamics of the levels of the IOP's and carbon constituents. The software uses existing Java code modified to use with our images. Since the code is written in Java, it is platform independent thus permitting more users access to the data without having to design a separate set of tools for each operating system.

Software was developed to permit the calibration and processing of data acquired with the OCLI MicroPac sensor. The set of programs, *micropac_clean* and *micropac_parse* remain in a state of development as calibration and testing of the new instrument continues into the next reporting period. The instrument was flown along side the ADAS sensor on a number of EstHab01 missions. The initial processing of the data from the MicroPac sensor indicates that the new spectroradiometer may be an inexpensive replacement for the ADAS that will provide ocean radiance data of comparable quality.

Considerable effort during the last 2 months has been spent on refining the global IOP SeaWiFS inversions. Global images have been created for all data produced by SeaWiFS to date. Also, eight smaller regions have had images generated for all the data so that the dynamics of these smaller areas can be studied in more detail. Analysis of these images is now underway. Another computer was purchased and configured to help store the hundreds of gigabytes of data produced so far and to help process the thousands of individual satellite passes into daily global means.

The calibration of the CDAS uplooking spectroradiometer was initiated during the previous reporting period. Cross correlation of the CDAS irradiance spectra with those obtained simultaneously with the SAS on clear days during a Mission conducted during March 19 as well as during a validation exercise conducted April 17 on the aircraft parking ramp at the NOAA Aircraft Operations Center in Tampa, FL revealed that there is ~20% disparity between the two sensors. Moreover, theoretical spectra calculated using *radtran* (a software package developed by Watson Gregg) for the time and location of the April mission revealed a disagreement with both the CDAS and the SAS sensors with the calculated spectra falling between the spectra from the two sensors. Additional work toward calibration of the CDAS sensor continues into the next reporting period.

Task 14 - Network Development and Maintenance

Initiated development of a program to read MODIS hdf files. Modified "alas", a program to read AOL data files for use in analyzing information obtained with the instrument operated in the pump and probe mode of operation.

Developed a system to take digital pictures every five or ten seconds using two Kodak DC4800 cameras and a linux laptop. The system logs when the photos are taken, the internal camera time, and the gps time and position. Other tools were developed to integrate the various log files back into a single file showing time and position of each photo.

Prepared systems for the Arctic 2001 mission.

Completed various system and network maintenance requirements.

Task 15 - Instrument Maintenance Engineering and Fabrication

Following the conclusion of the survey of Charlotte Harbor, the AOL instrumentation suite was removed from the Twin Otter at the NOAA Aircraft Operations Center in Tampa, FL. The instrumentation was transported to WFF via a rental truck.

Development of the OCLI MicroPac system was continued during the reporting period. The MicroPac was tested in the calibration lab and found to be about 2 times more sensitive than the ADAS unit. The MicroPac was co-mounted under the ADAS telescope for flight testing, and data was collected during many of the Spring 2001 Esthab missions for comparison. Preliminary processing shows the MicroPac holds real promise for a low cost alternative for the ADAS system, at a slower data rate. Processing is continuing. Analysis of data collected with the OCLI MicroPac system continues into the next reporting period.

No additional work was performed under Task 15 on the AOL sensor suite during this reporting period. The instrumentation was placed into storage for use during the next field campaign which is currently scheduled for November on the NASA P-3B aircraft.

Airborne Topographic Mapper (ATM)

Task 11 - Mission Planning and Execution and Sensor Operation and Calibration

We finalized the detailed mission plans for five ATM flights over southern Greenland. Mainly conducted over the periphery, these flights had the primary purpose of revisiting several of the outlet glaciers that had been previously mapped, and either never revisited, or had been revisited and had shown large changes. We also incorporated several other requests from the Greenland science community into the flight plans, notably a request to fly along the central dividing ridge to support layering studies, which we accommodated by incorporating the desired line into two separate flights. We performed a number of checks on the flight plans to verify that they accomplished the desired objectives. As part of this process we iteratively refined the waypoints so that as much of the missions as possible could be flown using great-circle navigation. This will alleviate stress on the pilots and ensure better repeatability of the flight lines. The missions were successfully conducted during the latter part of May.

We continued with detailed flight planning for the Western U.S. ICESat cal/val surveys. This proved to be a significant effort, largely because much of the terrain in the desired area is quite rugged and difficult or impossible to fly using the terrain-following approach required by the ATM. We used this information to select several individual ground tracks of about 100 km in length, and verified that they were in fact flyable by designing a conservative P-3 altitude profile for each track. We used this altitude profile to show that the required rates of climb were well-within the capabilities of the P-3, and that the corresponding altitudes above terrain would allow for suitable surveys given the altitude and swath limitations of the ATM. Finally we summarized these conclusions, designed a set of three detailed flight plans, and presented them to members of the ICESat Science Team for their approval. Finalization of these plans is proceeding.

Field missions to be conducted over the Dry Valleys of Antarctica during next December/January were re-planned in detail following additional input from USGS. It was determined that the entire area of interest could be surveyed in approximately 17 mission and that the survey could be completed along with the requested surveys by USGS within the ~4 week time frame allocated for the ATM Antarctic deployment. Cost estimates were also refined for a proposed survey of the Byrd Glacier in the winter of 2002/2003. A proposal was developed and submitted to NSF through *Fast Track* (a required internet proposal submittal web-based program). The proposal to NSF was for logistical support for the acquisition of the data. A companion proposal for salary and travel support is being prepared for submission to NASA HQ in the next reporting period. The Byrd glacier work would be conducted in collaboration with Dr. Terry Hughes and colleagues at the University of Maine.

Installation of GPS, GPS navigation, ATM2a and ATM3 equipment onboard the NASA P-3B aircraft was completed. Because of the requirement for operating GPS base stations in both Greenland and Iceland simultaneously for the transit/data mission between Iceland and

Greenland, two sets of GPS ground station equipment were prepared with accompanying import/export paperwork and shipping documentation for customs clearance. One of the units was hand-carried thru Canada by John Sonntag, the other was shipped back to Wallops from Iceland.

In addition to supplying GPS support for the seven data missions of the 2001 Arctic deployment, position verification data was collected (a minimum of 48 hours of continuous ground station operation) for both the Keflavik and Kangerlussuaq primary survey marks. A ramp survey was performed in Iceland and two remote sites in Greenland were occupied for inter-year comparison.

The instrumented P-3B aircraft transited from WFF to Keflavik, Iceland on May 17 as scheduled. A mission to map the volcanic island of Surtsey was flown on May 18. The outwash plain of Sandur was surveyed along two main channels and in the region south of the calving point of the glacier on a mission conducted on May 19. In addition, two passes were made over the Vatnajökull Ice Sheet as part of the May 19 mission.

Two missions over outlet glaciers in eastern Greenland were staged from Iceland in order to reduce the cost of acquiring the data. (Fuel costs were considerably higher at the Sondrestrom Airport in Greenland than at the Naval Air Station at Keflavik, Iceland.) Favorable weather permitted the accomplishment of the two missions on May 20 and 21, respectively. May 22 was used as a mandatory crew rest day. Data was acquired during the transit flight from Keflavik, Greenland to Sondrestrom, Greenland on May 23. Specific targets on this mission were the ridge line of the summit of the Greenland Ice Sheet as well as surveys in the vicinity of the GRIP and GISP ice drilling sites near the summit. In addition, a pass was flown from GRIP to Swiss Camp and then extended to the edge of the ice sheet near Jakobshavn. A pass up the Jakobshavn Glacier was flown along a track previously occupied during missions conducted in prior years. A mission to map outlet glaciers over southern Greenland was flown on May 24. Weather precluded mission on May 25 and 26. A mission was flown on May 27 over Jakobshavn Glacier and along the 2000 meter contour north to Rinks Glacier. Persistent clouds surrounding Rinks Glacier prevented the conduct of a survey there. In addition, a series of 5 parallel flight lines separated horizontally by 15 m from one another were flown for testing of the University of Kansas CARDS ice penetrating radar. The P-3B then transited from Sondrestrom, Greenland to WFF on May 28.

Task 12 - Data Processing Cataloguing and Archiving

Archiving and inventorying of the Arctic Ice Mapping (A.I.M.) '00 flights from 5/20/00 to 6/2/00 were completed. The processing of the data acquired during the December, 2000 survey of the Puerto Rico coastline was completed. The data from the Puerto Rico project was processed through quality assurance programs and found to be consistent. The data from the 7 missions flown over Puerto Rico were copied to CD-ROMS and were distributed to Dr. Aurelio Mercado

of the U. of Puerto Rico and to Dr. John Brock of the USGS Center for Coastal Geology in St. Petersburg, FL.

Task 13 - Data Analysis Interpretation and Reporting and Laboratory Analytical Support

Completed analysis of Canadian ATM dh/dt with USGS landcover and topography maps. The original objective had been to extrapolate the dh/dt measurements to each entire icecap based on the relation of dh/dt to elevation. Software was developed which generates a map for a given ice cap (on a 800x1150 grid). It extracts the USGS both the landcover and topography for the specified region and the ATM dh/dt measurements. The ATM data is put on the same grid, clipped to the defined ice areas (using the landcover map and a polygon outline that defines a particular icecap), and plotted on the maps using a color coding. For each ice cap a graph was also generated of dh/dt vs. elevation derived from the gridded maps. The relation of dh/dt to elevation was found sometimes to be complex, however. In most cases there was a trend of faster thinning at lower elevations, however the slope of the trend was different for each of several flight lines on a single icecap. The Prince of Wales icecap showed two different behaviors in the north vs the south. The results were discussed with the PI (Waleed Abdalati/ NASA HQ) and found to be sufficient. It was decided that the original objective did not suit what was revealed in the analysis of the measurements.

Two ATM systems were deployed to Iceland and Greenland on the NASA P-3 aircraft May 17-28. Performance of the instruments were checked prior to installation, after installation, and in tests conducted before and after every mission flight. Two Sun computer systems were set up in the dormitory in Iceland for analysis of flight data and for mission planning. A PC/linux system was also set up for transferring data to the Suns and for making backup copies of the flight data onto multiple hard disks.

The digitization of the Puerto Rico shoreline using ATM 3 data was completed. The digital shoreline will be used by Dr. Aurelio Mercado-Irizarry of the University of Puerto Rico..

Proposed flight-time estimates for the upcoming Antarctic missions were refined and recalculated. Logistics questions regarding the operation requirements at Williams field (McMurdo) were addressed with our USGS representative.

Archive data from the 1991 and 1992 Greenland field seasons was located and downloaded in preparation for expanding the Jakobshavn Basin multi-year dataset. These two years will be compared against the intensive gridded basin survey of 1997. Data from 1993, 1994, 1995, 1998 and 1999 was compared to the 1997 dataset to determine annual rates of change in the basin area. The ultimate goal is to compare the yearly change rates measured by the ATM laser systems to degree-day information collected at weather stations near the Jakobshavn glacier. The analyses are being done in conjunction with Dr. Robert Thomas (EG&G) and Dr. Waleed Abdalati of NASA HQ. Proposed flight-time estimates for the upcoming Antarctic missions were refined and recalculated. Logistics questions regarding the operation requirements at Williams field

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In view of the need to determine INS pitch and roll errors over rough surfaces, particularly vegetated surfaces, software was developed to compute pitch and roll errors for ATM crossings when the surface around the crossing point cannot be modeled as a set of planes, as is assumed by the programs *surdif* and *surdify*. The model used for *alignqfit* was adopted, namely to compute height differences for surface points which are within some separation distance, such as 2 m, and ignore surface slopes. Partial derivatives for the variation of height differences with respect to pitch and roll were calculated using the same expressions used in the *cres* program. Pitch and roll are obtained from the *qfit* file, and ATM range is calculated approximately based on the *qfit* surface elevation and the aircraft height at the crossing point. Estimated parameters include pitch and roll errors for the two passes and the mean height difference between the passes. Also calculated are the rms fit before and after parameter estimation. Results for the INS errors, using a 2 m search radius, are:

Date	No. of Crossings	Pitch		Roll	
		mean	rms	mean	rms
970513	68	0.023 deg	0.022 deg	-.033 deg	0.017 deg
970515	70	0.011 deg	0.029 deg	-.031 deg	0.028 deg

This summary includes all crossing points. Some 70% of the crossings have fits of 10 cm or better after the 5 parameter adjustments. However, the only significant change when editing crossings with high noise fits is to reduce the roll rms on 970515 to 0.019 deg. These results show that INS errors can significantly impact the estimation of mounting biases using ramp passes, and probably in a systematic manner. A variation of the crossing pass analysis program was made to estimate only pitch errors and use differences between forward and backward scans as the measurement input. Agreement with the crossing program over Jakobshavn was generally good. However, the program was also used to calculate pitch errors for ramp passes for both of these days. For 970513, the mean pitch error was around 0.012 deg (nearly the same for both pre-mission and post-mission passes), but was -.031 deg for the post-mission pass on 970515. The need for a more accurate attitude measurement system is thus very compelling.

Ramp passes for 11 May 2001 were processed for both ATM2 and ATM3. ATM3 shows good fits, but with a range bias on the order of 8-9 cm. ATM2 was quite noisy, presumably due to a subsequently fixed problem in measuring received pulse energy.

Task 14 - Network Development and Maintenance

See the Task 14 discussion for the AOL sensor (above). Tasks described in that section apply to the ATM sensor support in this section.

Task 15 - Instrument Maintenance Engineering and Fabrication

All GPS computers containing external-only hard drives were modified to move the hard drive to an internal location, and enable the removable hard drive slot to be used for data back-up (6 computers modified). This allowed much faster, and non-network required backup of data during the 2001 Greenland missions.

The ATM1 system was re-racked, the detectors changed from a two PMT system to a smaller Hamatsu PMT detector, and the electronics coupled to the smaller 15° transceiver. This new system is designated ATM2a. The electronics and 22° transceiver are collectively designated ATM3.

The previously reported ATM2a computer motherboard failure was repaired using another motherboard, and the ATM2a system (the re-racked ATM1 data system, and the ATM2 transceiver combination) brought to operation status, and ground tested.

The dual digital camera system (camget) was completed and installed on the P3 aircraft over a small photo port aft of the ATM2a system. The camget system takes digital images from two Kodak 4800 digital cameras on an alternating basis, resulting in an images every 5 seconds during flight. The laptop computer which controls the camget system was installed on top of the ATM2a rack, and can be operated by the person running ATM2a.

Both the ATM2a and ATM3 systems were installed on NASA 426 P3 aircraft, along with all support systems (GPS, INS, aircraft data computer, Navigation computers). All systems were ground tested, tested flown on May 10, and deployed for the Iceland/Greenland 2001 missions from May 17 to May 28. 8 missions were successfully flown during that time period.

Preliminary designs were developed for instrumentation racks to be used on Twin Otter aircraft. This engineering effort is being pursued in cooperation with the aeronautic engineering staff at the NOAA Aircraft Operations Center in Tampa, FL. These racks will require FAA approval and are a requirement for survey work to be done in Antarctica in December, 2001 and January, 2002. Work on the Twin Otter instrumentation racks will continue into the next reporting period.

Scanning Radar Altimeter (ATM)

Task 1 - Mission Planning and Execution and Sensor Operation and Calibration

No activity during reporting period.

Task 2 - Data Processing Cataloguing and Archiving

No activity during reporting period.

Task 3 - Data Analysis Interpretation and Reporting and Laboratory Analytical Support

No activity during reporting period.

Task 4 - Network Development and Maintenance

No activity during reporting period.

Task 5 - Instrument Maintenance Engineering and Fabrication

Modifications were made to the SRA so that it could be installed in a smaller rack within the NOAA Hurricane Hunter P-3C aircraft. To accomplish this task, the front panel of the transmitter and exciter were removed to avoid vibration generated by the bandsaw in trimming the front panel. The SRA is scheduled for installation on the NOAA Hurricane Hunter P-3C aircraft in mid June. In preparation for this scheduled deployment the dectector/amplifier was checked as a possible source of operator complaints about an abnormal looking start pulse (transmitter-detected pulse). A bench test confirms that the amplifier is O.K. but it does have considerable ringing on the output if left unterminated. Also Checked Exciter output after reassembly.:

L.O.Output w/30db. atten.. +6.5 dbm (same as prev.)
Xmtr. " " " +7.3 dbm (test on 3/21/01)
(using 30 db Ref. Atten. S/N 42244)

Fixed up a delay cable for Wayne Wright to use on EAARL, (a roll of RG-142 with connectors on both ends). Have now made (4) of these, 100 ft. each. 4/26 -5/31 Started work on the new GPS receiver circuit boards, ordered parts, and began assembling parts to boards and making jumper cables, etc. Assembly and checkout continues thru the end of the reporting period.

There are (12) of new GPS receiver packages consisting of a processor, GPS rcvr., dual hard drives, a voltage regulator, with a communications board for fanout to various external devices. So far we've got six good boards assembled and only 4 hard drives checked out, with some processor and hard drive problems. Work on the GPS receivers will continue into the next reporting period

Additional work under Task 5 included some fabrication work for the WEIRDO rain measuring instrumentation, modification of modules for units used in the TRMM experiment.

Al Waller attended a 1 week seminar in Rockville, MD for training in the use of National Instruments hardware and software, *Labview* version 6.0. In addition, Al attended 2 CAMEX-4 planning video conferences. Al also installed and debugged a new version of balloon tracking software in preparation for CAMEX-4 field mission.

Continuing development on Ozone lab calibration systems. Planning was initiated for a 6 week field program at Andros Island, Bahamas with Frank Schmidlin. The field program is planned for the period from August 13 to September 27.

Built portable antennas and delivered a portable balloon tracking data system, loaned to the Navy by NASA.

Developed a method to test GPS radiosondes indoors by retransmitting the L band signal from an external antenna. Specified the external antenna and installed a broadband digital satellite system for high speed Internet access in remote areas. Modified the system to allow up to 8 users on a network to have independent access to the satellite.

Developed a method to use Omni directional and yagi antennas simultaneously on the same data system

Developed a method to use 2 data systems on a single antenna.

Bimonthly Progress Reports for Contract NAS5-99094

Glossary of Acronyms

<Current as of April 23, 2001>

ADAS	Airborne Diode Array Spectrometer
AGC	Automated Gain Control
AGL	Altitude Above Ground Level
ALACE	Airborne Lidar Assessment of Coastal Erosion (joint NASA/NOAA/USGS program to measure changes in coastal morphology)
AIM	Arctic Ice Mapping (NASA program to measure the mass balance of arctic ice sheets such as the massive ice sheet covering Greenland)
AOC	NOAA Aircraft Operations Center (Macdill AFB, Tampa, FL)
AOL-3	Airborne Oceanographic Lidar (version 3 put into service in March, 1998)
ASA	Airborne SeaWiFS Simulator
ATM	Airborne Topographic Mapper (Versions 1 and 2 are both in current use)
CDAS	Cosine Diode Array Spectrometer
CDOM	Chromophoric dissolved organic carbon
CIMEL	Automated Sun-tracking photometer
CCG	USGS Center for Coastal Geology (St. Petersburg, FL)
CSC	NOAA Coastal Services Center (Charleston, SC)
DAAC	Distributed Active Archive Center
DEM	digital elevation model
DL	Down-Looking Scatterometer
EAARL	Experimental Advanced Airborne Research Lidar sensor
EstHab	Estuarine Habitat Project - joint NOAA/NASA initiative to study coastal waters and to evaluate remote sensor performance in these environments.

EEQ	Excessive Energy Quenching
FRRF	Fast Repetition Rate Fluorometer (shipboard instrument)
GAC	Global Area Coverage (ocean color satellite imagery)
GLAS	Geodetic Laser Altimeter
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
ICESat	<i>Ice Cloud and Land Elevation Satellite</i>
IOP's	Oceanic Inherent Optical Properties (chl absorption, CDOM absorption and total constituent backscatter)
JGOFS	Joint Global Ocean Flux Studies
IR	Infrared
IOP's	Inherent Optical Properties (of sea water)
LAC	Local Area Coverage (ocean color satellite imagery)
MAB	Middle Atlantic Bight (of the western North Atlantic Ocean)
NEGOM	Northeast Gulf of Mexico (Texas A&M Cruise)
NOAA	National Ocean and Atmospheric Administration
NRC	National Research Council (personnel)
OSD	Operations and Safety Directive (required by GSFC Safety for all airborne programs)
PARCA	NASA Program for Arctic Regional Climate Assessment
P&P	Pump and Probe (lidar methodology for measuring photo synthetic rate parameters)
PRF	Pulse Repetition Frequency
ROWS	Radar Ocean Wave Scatterometer

R/V	Research Vessel
SAFire	A shipboard spectrometer for measuring CDOM fluorescence
SAS	SeaWiFS Airborne Simulator (NOAA CSC sensor)
SeaWiFS	Sea-viewing Wide Field-of-View Sensor (satellite ocean color scanner)
SeaDAS	SeaWiFS Data Analysis System (processing and display software)
SLF	Shipboard Laser Fluorometer
SP-P&P	short pulse Pump and Probe
SST	Sea Surface Temperature (captured from the Heimann IR Radiometer)
USGS	U.S. Geological Survey
UV	Ultraviolet
WEIRDO	Wallops Enhanced Imaging Rain Drop Observer
WFF	Wallops Flight Facility

Computer Programs

<i>gitar</i>	ATM project software for phase code tracking differential GPS data
<i>gypsy</i>	Jet Propulsion Laboratory software for positioning a fixed GPS receiver
<i>mplot</i>	AOL project plotting software to produce multiple plots per page